GREENBOOK NATURAL RATES FOR UNEMPLOYMENT AND INFLATION: ACCOUNTING FOR THE GREAT INFLATION

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Abstract: This paper exploits the multiperiod format of historical briefing forecasts prepared for the Federal Open Market Committee to provide new evidence on the evolution of central bank perceptions of natural rates of economic activity and on historical changes in the design of US monetary policy. Empirical results support a neglected interpretation of policy during the Great Inflation of the 1970s.

Keywords: Asymmetric information; time-varying natural rates; the Great Inflation.

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1 Introduction

Natural rates are important, but infrequently discussed, components of macro models that describe equilibrium levels of economic activity and anchor agent expectations. Defined by Frisch (1936) as equilibrium solutions of models in the absence of dynamic frictions, natural rates are often neglected background scenery in theoretical macro models that recast variables in equilibrium-deviation or "gap" formats. Even with real-world experiences of stagflation and the slowdown in trend growth in the 1970s, time-variation in natural rates could be ignored in theoretical models that assumed full information on the size and timing of structural breaks. The assumption of full information and the general absence of explicit analysis of time-varying natural rates continued to be prevalent with the development of New Keynesian (NK) policy models in the mid-1990s. These models generally contained an output gap, with deviations in output from a time-varying natural rate, and invariant natural rates for inflation and the real interest rate. [1]

At the same time, empirical treatments of natural rates were limited. One way of dealing with varying natural rates was to use "trends" that were preconstructed outside of a structural macro model. Common examples of trend constructions included polynomial functions of time, univariate Hodrick-Prescott (or band-pass) filter estimates, and Beveridge-Nelson (1981) time series partitions, all of which were used primarily with growing series such as the natural rate of output. In some cases, invariant natural rates were assumed to be implicit in equation intercepts, as was frequently the case for the unemployment natural rate in Phillips curve specifications. A more restrictive, but not uncommon, approach was to assume a constant value for the unobserved natural rate—such as assuming the central bank set a two percent inflation target.

Recent interest in structural change has raised questions about the validity of the full information assumption and the invariance of natural rates. Both of these issues turn out to be of critical importance for monetary policy. For instance, in most macro models, the principal transmission channel of monetary policy is the long-term bond rate, which depends on current and anticipated future settings of the policy rate as well as a term premium. However, early empirical implementations of forward-looking macro models indicated long-term bond rates were not a reliable transmission channel for monetary policy, a property that tended to discourage use of forward-looking models in practical monetary policy analysis. These pessimistic assessments can be explained by unrealistic assumptions that the natural rates of inflation and the real interest

[1] This mixture of a time-varying natural rate for output and invariant natural rates for the remaining state variables is a staple of the models discussed in the influential volume edited by Taylor (1999).

rate are constant and known by all economic agents.[2]

In exploring alternative descriptions of policy transmission, two significant alterations in the natural rates of short-term policy models have been pursued in recent work. One modification is to relax the assumption of common information required by rational (model-consistent) expectations. An example is the asymmetric information case where the private sector does not directly know or believe the central bank target for inflation, $\bar{\pi}$, and the evolving private perception of this natural rate, π_t^p, is the relevant anchor for private agent forward expectations. Private agent learning is often represented by statistical estimators.[3]

Statistical learning alone is not always intrinsically interesting in large samples as many statistical learning models with unrestricted memory will converge, in well-behaved models, to the unknown natural rate. Consequently, the second modification extends time-variation to natural rates other than output, such as changes in the central bank's effective target for inflation, $\bar{\pi}_t$.[4]

Empirical studies of asymmetric information on natural rates, such as the central bank inflation target, $\bar{\pi}$, have been confined largely to estimating private sector perceptions, $\bar{\pi}_t^p$. By contrast, there is almost no empirical work on the other side of the information asymmetry–namely, the evolution of central bank estimates of natural rates, including possible time variation in the central bank target for inflation, $\bar{\pi}_t$.[5] To provide a central bank baseline for natural rate perception errors, such as $\bar{\pi}_t^p - \bar{\pi}_t$, the current paper presents measures of the central bank estimates of selected natural rates, based solely on the policy actions of the Federal Open Market Committee (FOMC) and the real-time macro forecasts presented to the FOMC during its policy deliberations.

Estimation of central bank perceptions of natural rates will also sharpen the focus of ongoing debates regarding historical monetary policy. Theoretical exercises provide a large number of possible descriptions of the conduct of past policy. If we assume, for the purpose of discussion, that a Taylor-type rule for the

[2] In particular, forecasts by empirical macro models with invariant natural rates for interest rates generate only modest variations in the average of policy rates expected over long-maturity horizons, suggesting that historical bond rates are dominated by movements in term premiums. The substantial "excess volatility" of historical long-term bond rates when the empirical macro model contains invariant natural rates is illustrated in Kozicki and Tinsley (2001a, 2001b).

[3] Recent examples of calibrated learning in macro models include Orphanides and Williams(2003) and Bullard and Duffy (2004).

[4] Examples of empirical estimation of learning with time-varying $\bar{\pi}_t$ include the multinomial logit aggregation of private agent heterogeneous preferences for shift estimators of $\bar{\pi}_t$ in Kozicki and Tinsley (2001a) and fixed-gain learning by private agents of a time-varying specification of $\bar{\pi}_t$ in Kozicki and Tinsley (2003).

[5] A notable exception is the construction by Romer and Romer (2002) of central bank estimates of $\bar{u}_t$, which will be discussed in section 3. In the case of the natural rate for inflation, one reason for initial emphasis on private perceptions is the accessibility of real-time measures of private expectations, such as market prices of long-maturity assets and surveys of agent long-horizon expectations of inflation.

overnight policy rate controlled by the central bank,

$$r_t = \bar{\rho} + \bar{\pi} + c_2(\pi_t - \bar{\pi}) + c_3(y_t - \bar{y}_t) + \epsilon_{r,t}, \quad (1)$$

provides an adequate characterization of the responses of postwar US monetary policy, then the three natural rates (of output, $\bar{y}_t$, inflation, $\bar{\pi}$, and the real interest rate, $\bar{\rho}$) and two parameters of this equation fully describe the determinants of policy. Under this assumption, significant differences in one or more of these five arguments during the 1970s must necessarily explain the accommodative US monetary policy during the Fed chairmanships of Arthur Burns and William Miller. Indeed, if combinations of variations in the five arguments are considered, it would not be surprising if calibration exercises using alternative initializations of equation (1) could support $\sum_{i=1}^{5} \binom{5!}{i!(5-i)!}$ = 31 possible theories of policy failure during the Great Inflation. [6]

Turning to data-based interpretations of US monetary policy in the 1970s, there appear to be two leading candidate theories of the Great Inflation. [7] One interpretation has been labelled the *passive policy* explanation. In the influential work of Clarida, Gali, and Gertler (2000), this interpretation is supported by empirical estimates of the policy rate equation that indicate the estimated policy response of the funds rate in the 1970s did not keep pace with inflation. [8] One potential limitation of documented regression analyses of historical policy responses is that the central bank target for inflation is assumed to be invariant and captured in a fixed equation intercept.[9] A more subtle identification problem is raised by Beyer and Farmer (2004) where estimation of reduced form policy response functions, using only historical realizations of inflation and output, may be unable to distinguish between competing dynamic specifications of central bank responses and of other structural relationships in the macro system. Under asymmetric information, this source of ambiguity can be mitigated by using prior information on the structure of central bank forecast models and by fitting policy responses to the central bank historical forecasts.

The other leading explanation of the Great Inflation is the *natural rate error* interpretation. In a series of

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[6]Inconclusive calibration exercises of two competing theories of the Great Inflation are discussed in Collard and Dellas (2004). A concise survey of several interpretations of US and UK inflation in the 1970s is presented by Nelson (2004).

[7]A third policy-based interpretation is that the Fed attempted to exploit a perceived permanent tradeoff between unemployment and inflation, as in Sargent (1999) and Sargent, Williams, and Zha (2004). However, this theory is not supported by real-time implementations of the Phillips curve, as in Enzler and Pierce (1974), in which there was no long-run tradeoff.

[8]In terms of equation (1), the passivity of policy is summarized by the inequality, $\hat{c}_2 < 1$. Analytical determinacy conditions for a variety of interest rate response formats are explored in Woodford (2003). In the absence of a stable policy response to inflation, Clarida, Gali, and Gertler (2000) suggest that private sector expectations of inflation in the 1970s may have been driven by non-fundamental (sunspot) shocks.

[9]A sizeable literature explores regression estimates of US policy responses over postwar samples, including Judd and Rudebusch (1998), Taylor (1999), Romer and Romer (2002), and Nelson (2004).

important papers, Orphanides (2001, 2003a, 2003b) suggests policy responses in the 1970s to inflation and the output gap, such as c_2 and c_3 in equation (1), were consistent with stable policy responses. However, lower levels of the policy rate were induced by substantial and persistent overestimation by the central bank of the natural rate for output, $\bar{y}_t$. Although this research has instigated useful work on consequences of real-time errors in estimates of the natural rate of output and trend productivity, the applicability to policy formation in the 1970s is conjectural. A major obstacle to confirming this interpretation of monetary policy in the 1970s is the lack of a continuous historical record of central bank estimates of the natural rate for output. In the absence of evidence that staff estimates of $\bar{y}_t$ were routinely reported to the FOMC in the 1970s, Orphanides (2003a) uses output natural rates presented in annual reports of the Council of Economic Advisors (CEA) as a real-time proxy. Given representative specifications of aggregate pricing equations in the 1970s, it is more plausible that the FOMC gauged real resource slack by aggregate unemployment.[10] As with empirical investigations of the passive policy interpretation, regression estimates of policy responses using conjectural estimates of the natural rate for output also assume an invariant inflation target.

Using new measures of real-time central bank estimates of the natural rates for unemployment and inflation, this paper re-examines U.S. monetary policy in the 1970s. An important difference from prior studies is that the effective inflation target is not treated as implicit in fixed intercepts or assumed to be a known constant. While the empirical evidence confirms that real-time natural rate estimates of unemployment (and implicitly potential output) were below retrospective estimates, the errors are modest and do not appear to be the main determinant of low real funds rates in the 1970s. The empirical results generally support the passive policy theory of Clarida, Gali, and Gertler (2000). However, the results also suggest an alternative interpretation that provides additional insights into the design of US monetary policy in the 1970s.

The next section of the paper lays the framework for the subsequent empirical analysis. It sketches a NK theory of time-varying natural rates, introduces notation used to indicate our organization of central bank forecast data in historical Greenbooks, and discusses the several time series specifications used in subsequent sections to estimate natural rates. The first empirical section, section 3, presents estimates of

[10]CEA natural rate estimates are infrequently cited in the FOMC *Memorandum of Discussion* (MOD) during the 1970s, and do not appear to have been supported by staff forecasts. Examples include: "(T)he potential GNP as estimated by the Council of Economic Advisers is based on a 3.8 per cent unemployment rate. That may well be too low an unemployment target for sustainable economic growth without inflation," Partee, FOMC Economist (MOD, 11/17/1970, p.31) and "Mr. Partee observed that the target for the unemployment rate referred to in the Annual Report of the Council of Economic Advisers already seemed to have been increased from 4 to 4-1/2 percent....according to the (Greenbook) projections, even a 5 per cent unemployment rate would be associated with considerable continuing inflation in the short run." (MOD, 3/19/1973, p.28) .

time variation in the natural rate for unemployment implied by Greenbook forecasts. Section 4 discusses estimates of the natural rate for inflation implied by historical policy responses to Greenbook forecasts. The empirical results suggest a rethinking of the conduct of policy in the 1970s. Consequently, section 5 explores an alternative description of US monetary policy in that period. Finally, section 6 concludes.

2 Theory and practice of time-varying natural rates

Explicit consideration of natural rates raises several specification issues. First, natural rates are not directly observable. Consequently, a structural model is needed to identify which of its natural rates are invariant and which are time-varying. Furthermore, when recovering real-time estimates of natural rates, a methodological issue that needs to be addressed is whether it is valid to impose contemporary model specifications on real-time data from the 1970s and 1980s. Second, to evaluate real-time measures of natural rate estimates, real time data must be employed. In addition to complications inherent in any real-time analysis, the real-time forecast data necessary to construct central bank estimates of selected natural rates present computational challenges, such as differing forecast horizons across policy meetings, and different frequencies of policy meetings per year. Third, because the nature of the time-variation of unobserved natural rates is not obvious ex ante, several alternative dynamic specifications are plausible.

To address these specification issues, this section combines a "theory" of macro natural rates with a description of the methodology used to implement the "practice" of natural rate estimation. The theory discussion includes a sketch of natural rate determinants and relationships among natural rates within the context of the NK model, augmented to include an Okun's Law relationship. The latter is useful in capturing real-time specifications that tended to focus more on unemployment than output gaps. To implement this theory of natural rates, the "practice" discussion includes both an organization of historical Greenbook forecast observations that takes advantage of the multiperiod format of these forecasts and a catalog of the time series models used in this paper to identify the time-varying natural rates of Greenbook forecasts.

2.1 *Natural rates in the NK model*

While approaches to modelling dynamics and expectations have evolved over the past several decades, specifications of equilibrium relationships in macro models have remained relatively stable since the 1970s, such as log-linear production functions and vertical long-run Phillips curves. The NK model provides theoretical insights into determinants of the natural rates defined by equilibrium relationships. Intertemporal optimization and feedback rules were used to derive macro model specifications by the early 1970s, although forward expectations were often represented by distributed lags.[11] Thus, "as if" model specifications, such as variants of the NK model or of the "Taylor rule," are broadly plausible as characterizations of real-time models, and historical empirical models may have provided consistent, but inefficient, estimates of reduced form representations of models with explicit forward expectations.

A structural macro model, based on agent optimization, with policy feedback provides a starting point for formalizing discussion of natural rates. The framework used here is a simple three-equation version of the NK macro model:

$$y_t - \bar{y}_t = E_t\{y_{t+1} - \bar{y}_{t+1}\} - a_2 E_t\{\rho_t - \bar{\rho}_t\} + \epsilon_{y,t}, \tag{2}$$

$$\pi_t - \bar{\pi}_t = b_1 E_t\{\pi_{t+1} - \bar{\pi}_t\} + b_2(y_t - \bar{y}_t) + \epsilon_{\pi,t}, \tag{3}$$

$$r_t = \bar{\rho}_t + \bar{\pi}_t + c_2(\pi_t - \bar{\pi}_t) + c_3(y_t - \bar{y}_t) + \epsilon_{r,t}, \tag{4}$$

where the household demand for log output, y, and the inflation consequences of Calvo-type delayed price adjustments by monopolistic firms, π, are represented by equations (2) and (3). The remaining equation, (4), is a description of the overnight policy rate controlled by the central bank, r.[12] In standard formulations, all parameters are nonnegative, and the expectations operator, $E_t\{\,.\}$, denotes rational (model consistent) expectations. Anticipating examination of time-varying natural rates, the natural rates of output, $\bar{y}_t$, inflation, $\bar{\pi}_t$, and real interest rates, $\bar{\rho}_t$, are explicitly included in model equations and given time subscripts.

To improve the ability of this model to capture the real-time emphasis on unemployment rather than output, this standard NK model is augmented to include Okun's Law. The household demand for output, equation (2), and the inflation implications of pricing by firms, equation (3), are consistent with the following assumptions:

The representative household is infinitely lived and, in each period, consumes C_t, an index of differentiated commodities using a CES (Dixit-Stiglitz) aggregator. Purchases of consumption, bonds, and equity are financed by household income from financial assets and compensations for supply of labor, N,

[11] Euler equations were introduced to characterize the dynamic behavior of firms by Roos (1927); additional references on intertemporal optimization in economics and approximations of forward-looking producer behavior are discussed in Tinsley (1970). Forward-looking policy targeting was also employed by central bank staff analyses in the 1970s, vid. Kalchbrenner and Tinsley (1976). FOMC presentations of policy options used tablular or graphical analysis to illustrate judgmentally-adjusted model forecasts of predicted outcomes for alternative policy actions.

[12] Microfoundations of IS and Phillips equations, such as (2) and (3), are discussed in Woodford (2003). Equation (3) is an approximation of an NK inflation equation when $\bar{\pi} > 0$, as shown in Kozicki and Tinsley (2002b). Equation (4) is similar to monetary policy descriptions in Byrant et al. (1993) and Taylor (1993).

and labor utilization, X, to firms, where the range of labor supply is $0 \leq N \leq 1$. The allocation of income and the supplies of labor and utilization are determined by maximizing a discounted sum of expected utility,

$$E_t\{\Upsilon_t\} \quad = \quad E_t\{\sum_{i=0}^{\infty} ß^i \upsilon_{t+i}\}, \tag{5}$$

given the fractional discount factor, ß. Household utility in t is represented by a CRRA specification,

$$\upsilon(Q_{t+i}, C_{t+i}, N_{t+i}, X_{t+i}) \quad = \quad \frac{Q_{t+i}C_{t+i}^{1-\alpha} - 1}{1-\alpha} - \frac{N_{t+i}^{1+\gamma}}{1+\gamma} - \frac{X_{t+i}^{1+\delta}}{1+\delta},$$

where Q is a preference shock, and the parameters $[\alpha, \gamma, \delta]$ are nonnegative.

In the business sector, the production function of the ith firm is

$$Y_t(i) \quad = Z_t N_t^a(i) X_t^b(i). \tag{6}$$

Each firm has access to a common labor-augmenting productivity process, Z. The nominal cost of production for the ith firm is $W_t N_t(i) + V_t X_t(i)$, where the compensation rates for labor, W_t, and labor utilization, V_t, are also the same for all firms.

Conditioned on its labor input, the cost-minimizing labor utilization demanded by the ith firm is[13]

$$X_t(i) \quad = (\tfrac{b}{a})^{\frac{1}{1+\delta}} N_t^{\frac{1+\gamma}{1+\delta}}(i). \tag{7}$$

Using (7) to eliminate utilization from (6), the effective production function of the ith firm is represented as

$$Y_t(i) \quad = Z_t K N_t^{a'}(i), \tag{8}$$

where $K = (\frac{a}{b})^{\frac{b}{1+\delta}}$ and $a' = a + b\frac{1+\gamma}{1+\delta}$. Thus, conditioning only on household labor suggests that the effective short-run labor elasticity of production, a', may exceed unity if the supply of labor utilization is substantially more elastic than the supply of labor, $\delta \ll \gamma$.

Consistent with short-run real output effects of monetary policy, prices of differentiated goods in monopolistic product markets are sticky. Interpretations of the New Keynesian supply equation, (3), include quadratic costs or Calvo-delays in adjusting price levels. However, in a flexible-price equilibrium, the relative price set by the ith firm will be

$$\frac{\bar{P}_t(i)}{\bar{P}_t} \quad = \bar{\mu}\bar{\Psi}_t(i), \qquad \qquad \bar{\mu} \equiv \tfrac{\theta}{\theta-1}, \tag{9}$$

[13]As the discussion is focused on equilibrium relationships, we ignore friction specifications such as convex costs of adjusting the labor input.

where $\bar{\mu}$ denotes the equilibrium monopolistic price markup, θ is the price elasticity of demand, and $\bar{\Psi}(i)$ is the equilibrium real marginal cost of the ith firm,[14]

$$\bar{\Psi}_t(i) \quad = (aQ_t)^{-1}\bar{Y}_t^{\alpha}\bar{N}_t^{\gamma}\bar{Y}_t^{-1}(i)\bar{N}_t(i), \tag{10}$$

where $\bar{Y}$ and $\bar{N}$ denote indexes of aggregate equilibrium output and labor.

In a symmetric equilibrium, $P_t(i) = P_t, N_t(i) = N_t$, and $Y_t(i) = Y_t$. Consequently, equation (9) implies that the natural rate for output in a flexible-price equilibrium is

$$\bar{Y}_t \quad = (\tfrac{a}{\bar{\mu}})^{k_2}K^{k_3}Q_t^{k_2}Z_t^{k_3},$$

or, in logs, the time-varying natural rate of log output, $\bar{y}_t = log\bar{Y}_t$, is a linear function of the log preference shock, $q_t = logQ_t$ and log productivity, $z_t = logZ_t$,

$$\bar{y}_t \quad = k_1 + k_2 q_t + k_3 z_t, \tag{11}$$

where $k_2 = \frac{a'}{1+\gamma+a'(\alpha-1)}$ and $k_3 = \frac{1+\gamma}{1+\gamma+a'(\alpha-1)}$.

In NK models, the natural rate for the real interest rate may also be a time-varying function of preference shocks and the growth rate of productivity, vid. Woodford (2003). For example, evaluating the household first-order conditions underlying equation (2) at equilibrium gives[15]

$$\bar{\rho}_t \quad = \quad k_4 + \frac{k_3}{a_2}E_t\Delta z_{t+1} + \frac{k_2}{a_2}E_t\Delta q_{t+1}. \tag{12}$$

As noted in section 1, macro analyses of production resource constraints throughout the 1970s and 1980s were dominated by unemployment "gap" approximations of marginal cost, rather than by output gap representations. The log of the production function indicates that the natural rate of labor is

$$\bar{n}_t \quad = -\tfrac{1}{a'}logK - \tfrac{1}{a'}z_t + \tfrac{1}{a'}\bar{y}_t,$$

where $n_t = logN_t$. Thus, in the NK model, the natural rate of unemployment is

$$\begin{aligned} \bar{u}_t &= -\bar{n}_t, \\ &= k_0 - \frac{k_3 - 1}{a'}z_t - \frac{k_2}{a'}q_t, \end{aligned} \tag{13}$$

[14]First-order conditions for the household require $\frac{W_t}{P_t} = Q_t^{-1}C_t^{\alpha}N_t^{\gamma}$; and the cost-minimizing conditions for the ith firm require $\frac{W_t}{P_t} = a\Psi_t(i)\frac{Y_t(i)}{N_t(i)}$. Using the market clearing condition, $C_t = Y_t$, and eliminating the real wage yields the expression for real marginal cost in equation (10).

[15]The intercept, k_4, in equation (12) is a function of the expected covariation of the real rate and the stochastic discount factor, vid. Kozicki and Tinsley (2002a). Estimations of time-varying $\bar{\rho}_t$ using specifications similar to equation (12) are discussed in Laubach and Williams (2002) and Clark and Kozicki (2004).

where $k_0 = \frac{1}{a'}(logK - k_1)$. By equation (13), the natural rate for unemployment is invariant to shifts in productivity if $k_3 = 1$, which will occur if the utility of consumption is logarithmic ($\alpha = 1$).[16]

Finally, combining equation (13) with the log of the production function provides a New Keynesian variant of Okun's Law,

$$y_t - \bar{y}_t = -a'(u_t - \bar{u}_t). \tag{14}$$

Embedding this relationship into (3) and (4) results in expressions involving the unemployment rate and the unemployment natural rate—variables more frequently emphasized in historical policy debates than the output gap. After substitution, equation (3) becomes an unemployment-based Phillips curve,

$$\pi_t - \bar{\pi}_t = b_1 E_t\{\pi_{t+1} - \bar{\pi}_t\} - b_2 a'(u_t - \bar{u}_t) + \epsilon_{\pi,t}, \tag{15}$$

that will be used to construct real-time central bank estimates of the natural rate for unemployment in section 3. Equation (4) becomes a policy rule relating the policy interest rate to the natural rate for the nominal policy rate, defined as the sum of the natural rates for inflation and the real interest rate, the deviation of inflation from its natural rate, and the deviation of unemployment from the natural rate for unemployment:

$$r_t = \bar{\rho}_t + \bar{\pi}_t + c_2(\pi_t - \bar{\pi}_t) - c_3 a'(u_t - \bar{u}_t) + \epsilon_{r,t}. \tag{16}$$

This expression is used in section 4 to construct real-time estimates of the natural rate for inflation.

One source of time-variation in the US natural rate for inflation, $\bar{\pi}_t$, is through changes in the effective preferences of the central bank policy committee. Although an individual decision-maker may maintain an invariant preference distribution over the domain of natural rate objectives, the historical record of FOMC discussions suggests differences in preference distributions among members of the FOMC. Because US monetary policy is determined by a twelve-member subset of the FOMC, rotations of voting eligibility and of tenure on the FOMC, as well as variations in framing voting choices, vid. Arrow (1951), imply that the effective natural rate for inflation selected by the central bank will likely vary over time.

2.2 *Characterizations of Greenbook natural rates*

The equilibrium properties of the simple NK model sketched in the preceding subsection suggest empirical work should allow for time variation in natural rates. However, there appears to be no consensus macro literature on the dynamic specifications of natural rates. A standard estimation approach to invariant natural

[16] Comovements of labor productivity and of actual and perceived natural rates of unemployment under lagged learning are explored in Ball and Mankiw (2002) and Reis (2003).

rates is to collect them into fixed intercepts of model equations. In the case of time-varying natural rates, a common specification is the random walk structural time series model. Other studies use smoothing filters.

Ambiguity in dynamic specifications of natural rates may stem, in part, from different contexts of use. In some applications, the natural rate appears to be interpreted as a time series attractor such as the mean, if the series in question is stationary, or a cointegrated trend, if the series contains a unit root.

In analyses of natural rate "gaps," the concept often follows that of Frisch (1936) where *instantaneous* natural rates of macro models are, by construction, equilibria for a subset of variables and conditioned on the current values of the remaining states.[17] Under this specification, even if the real interest rate is stationary, for example, the associated instantaneous natural rate may vary from period-to-period as it is conditioned on values in t of hidden or unobservable variables such as the current growth rate of productivity and current preferences of agents as demonstrated above for the NK model.

In the case of anchoring long-horizon forecasts, such as implicit in modelling long-maturity bond rates, the *asymptotic* natural rate anchor for forecasts of the real interest rate, for example, is the infinite-horizon forecast, $\bar{\rho}_t = \lim_{k\to\infty} E_t \rho_{t+k}$.[18] If the real interest rate is a stationary stochastic process, the associated asymptotic natural rate is a constant, often approximated by a long-sample mean. Alternatively, if the real interest rate contains a unit root, the asymptotic natural rate will vary in each period and is represented by a moving average of recent observations, which includes a random walk as a special case.

In the present context of specifying the natural rates of the undocumented Greenbook forecast model, it seems appropriate to allow for time-variation in all natural rates but to explore stationary, as well as nonstationary, representations. Even if the forecast model of a given Greenbook contained one or more fixed natural rates, it seems likely that estimates of these rates will have varied over time due to expanding samples and rotations of forecast assignments, as well as other factors noted later.

A versatile model for estimating time-varying natural rates is the time-varying parameter (tvp) specification. Our primary emphasis is on structural macro relationships, such as an unemployment gap variant of the pricing equation in equation (3)[19]

$$\pi_t = b_{1,t} + E_t\{\pi_{t+1}\} + b_{2,t} u_t, \tag{17}$$

[17] A notable example is Woodford's (2003) revival of the Wicksellian natural rate of interest under flexible pricing.

[18] Kozicki and Tinsley (2001a, 2001b) associate the term "endpoints" with long-run asymptotic natural rates.

[19] Equation (17) is a simplified version where the coefficient of expected inflation, b_1 in equation (3), is set to unity. This is a reasonable approximation if the household discount factor, ß, is near one, see Table A1 in Kozicki and Tinsley (2002b).

where the natural rate of unemployment is $\bar{u}_t = -\frac{b_{1,t}}{b_{2,t}}$. However, we also discuss examples of atheoretic time series models, such as the k-th order autoregression,

$$u_t \quad = b_{1,t} + b_{2,t}u_{t-1} + \sum_{j=2}^{p} b_{j+1,t}\Delta u_{t-j+1}, \tag{18}$$

where the estimated natural rate is $\bar{u}_t = \frac{b_{1,t}}{1-b_{2,t}}$. The autogressions are presented to illustrate some shortcomings of reduced form constructions of natural rates, especially under asymmetric information.

Data are drawn from historical Greenbooks. The Greenbook (GB) is a staff briefing document presented to FOMC members during a policy meeting of the FOMC. Part I contains background analyses of recent economic and financial data, and Part II presents the staff multiperiod forecast of economic activity. The baseline Greenbook forecast is a "judgemental" forecast. Components of the forecast are selected in a series of meetings by the senior staff and sectoral specialists, who prepare initial projections for their area of expertise. Although forecast preparation meetings include forecast inputs from economy-wide econometric models, such as the quarterly MPS model (used from the late-1960s through the mid-1990s),[20] the dominant inputs are sectoral forecasts from staff specialists. In addition to monitoring a broader set of high-frequency data releases than are incorporated in the economy-wide quarterly model, each specialist generally considers forecasts from a range of alternative sectoral models before formulating a sectoral forecast.

The baseline Greenbook forecast is considered the modal, or most-likely, outcome, given recent policy decisions and objectives. Forecast assumptions conditioned on perceived current policy and objectives include the senior staff's judgement of likely outcomes in financial markets over the forecast horizon, including the behavior of intermediate- and long-term interest rates. These forecast conditioning assumptions are not systematically recorded in FOMC documents redacted by the FOMC Secretariat.

Because the Greenbook forecast model is judgemental, its equations are not formally documented. Thus, an econometric reconstruction of the implicit macro model underlying GB judgemental forecasts confronts many of the same problems as do estimations of macro models from government agency measurements of economic activity. There are some advantages, however, including real-time records of agency measurements and of the judgemental multiperiod forecasts generated for each Greenbook. For example, in the case of equation (17), the forecast generated in period t contains not only staff forecasts of π_t and u_t, but also the forecast of next quarter's inflation, $E\ _t\pi_{t+1}$.

[20]Although forecasts by the staff quarterly model are referenced as a benchmark check on judgemental forecasts, the primary FOMC products of the quarterly model are simulations of alternative forecast scenarios and policy options that differ from the assumptions of the baseline GB forecast.

To introduce a more general model notation, the forecast of a variable in the current quarter, y_t, reported by a Greenbook generated in t_g is represented by

$$y_{t|t_g} = x'_{t|t_g}\beta_t + a_{t|t_g}, \qquad t_g = 1, \ldots, T_g, \tag{19}$$

where the t_g date is contained in quarter t ($t-1 < t_g < t$); the x vector may contain leads or lags of explanatory variables; and a is a measurement error to account for unobserved forecast arguments that are not contained in the historical record of Greenbook forecasts. The h-quarter-ahead forecast is denoted by

$$y_{t+h|t_g} = x'_{t+h|t_g}\beta_t + a_{t+h|t_g}, \qquad h = 0, \ldots, H_{t_g}, \tag{20}$$

where H_{t_g} indicates the forecast horizon for the Greenbook in t_g. Unless otherwise indicated, all variables denote GB forecasts or measurements, not current (retrospective) measurements. Also, as the originating date of a representative GB forecast is contained in quarter t, the conditioning subscript, t_g, is generally dropped in subsequent discussion to ease notation.

The sample used in this paper includes the 126 quarters from 1966Q3 through 1997Q4, a span that contains 315 Greenbooks. Greenbook forecasts were more frequent in early years of the sample, but the frequency has remained at eight per year since 1981. The average forecast horizon, $H+1$, is 5.7 quarters. However, as shown in Figure 1, the forecast horizon was much shorter in the 1960s and early 1970s, sometimes including only the current quarter, $H = 0$. Typically, the forecast horizon is longest for Greenbooks prepared before the semi-annual congressional testimony of the Fed chairman, and then diminishes in the next few Greenbooks with the passing of each subsequent quarter.

An important assumption of analysis in this paper, illustrated in equation (20), is that the same model is used to predict the multi-period forecasts in a given Greenbook. In other words, the parameters of the linear forecast model, β_t, are invariant across forecast periods within the forecast horizon, $h = 0, 1, \ldots, H_{t_g}$. This is not always a tenable assumption, and an approximate adjustment is discussed later. However, the structure of the Greenbook forecast model, encapsulated in the parameter vector, β_t, may vary in succeeding Greenbooks or calendar quarters. An incomplete list of reasons for variation in the Greenbook forecast model includes: new developments in economic or econometric theories of macro modelling; recent forecast performances of competing sectoral models; rotation of staff forecast assignments; replacement of senior staff and forecast coordinators; and inquiries from members of the FOMC.

2.3 *Alternative time-varying parameter (tvp) estimators of natural rates*

Stacking the multiperiod forecasts associated with Greenbooks in period t gives the *measurement* equation,[21]

$$\begin{aligned} y_t &= \Xi_t \vec{\beta}_t + a_t, \\ &= [\tilde{X}_t, X_t] \begin{bmatrix} \tilde{\beta}_t \\ \bar{\beta} \end{bmatrix} + a_t \end{aligned} \tag{21}$$

where the dependent variable, y_t, and the measurement error, a_t, are equal length vectors to account for the number of observations in period t. The matrix of regressors, $[\tilde{X}_t, X_t]$, conforms to the dimensions of y_t and the parameter vector, $[\tilde{\beta}_t, \bar{\beta}]'$, and X_t contains k regressors, including a unit vector. The $\vec{\beta}_t$ vector is partitioned into a $k \times 1$ fixed vector, $\bar{\beta}$, and a $\tilde{k} \times 1$ time-varying vector of deviations, $\tilde{\beta}_t$, whose unconditional mean is zero. The effective time-varying coefficients of the forecast model, β_t, are obtained by summing the fixed and time-varying deviation vectors

$$\beta_t \equiv \bar{\beta} + \begin{bmatrix} \tilde{\beta}_t \\ 0_{k-\tilde{k}} \end{bmatrix}, \tag{22}$$

where $0_{k-\tilde{k}}$ is a $(k - \tilde{k}) \times 1$ zero vector. Note that $\tilde{k} < k$ if the last $k - \tilde{k}$ elements of β_t are invariant over time.[22] The measurement error is normally distributed, $a_t \sim N(0, R_t)$. In most applications, $R_t = \sigma_a^2 I$, but in some examples σ_a^2 varies over subsamples.

The format of the *transition* equation is

$$\vec{\beta}_t = \Phi \vec{\beta}_{t-1} + e_t, \tag{23}$$

where the partitions of the transition matrix and the transition shock vector are

$$\Phi = \begin{bmatrix} \tilde{\Phi} & 0 \\ 0 & I_k \end{bmatrix}, \text{ and } e_t = \begin{bmatrix} \tilde{e}_t \\ 0 \end{bmatrix}. \tag{24}$$

The nonzero transition shocks are also normally distributed, $\tilde{e}_t \sim N(0, \tilde{Q})$.

We consider three different specifications of time-varying regression parameters that have appeared in the macro literature. Each amounts to different restrictions on the dimension of the time-varying partition, $\tilde{\beta}_t$, and on the eigenvalues of the associated transition matrix, $\tilde{\Phi}$. As the competing specifications make

[21] Each calendar quarter contains more than one Greenbook. To provide some smoothing of β_t estimates, forecast observations from the Greenbooks of a single calendar quarter will often be stacked in a quarterly measurement vector or matrix.

[22] The matrix $\tilde{X}_t$ is a subset of X_t when $\tilde{k} < k$. Also, the t subscript is generally reserved for either Greenbook periods, $t = 1, \ldots, T_g$ or calendar quarters, $t = 1, \ldots, T_q$. In some instances, it is useful to refer to components of a single forecast in the stack of all Greenbook forecasts by the τ subscript, $\tau = 1, \ldots, T$, where $T = T_g + \sum_{t_g=1}^{T_g} H_{t_g}$.

different assumptions about the scope and persistence of time variation in the model structure, and we did not initially have strong priors over these alternatives, all three specifications are estimated in each application.

random walk intercept (RWI)

A widely-used specification of time-varying natural rates in recent macro papers rests on the assumption that the intercept follows a random walk, $\beta_{1,t} = \beta_{1,t-1} + e_{1,t}$.[23] As noted by Stock and Watson (1998), if the variance of the random walk transition shock, $\sigma^2_{e_1}$, is small, the maximum likelihood estimate may be biased toward zero. Consequently, we use the Stock and Watson median-unbiased estimator of the variance of the transition shock, $\sigma^2_{e_1} = \hat{\nu}^2\sigma^2_u$, where u denotes residuals of the fixed-coefficient regression, $y_\tau = X_\tau\bar{\beta}$, and ν is a function of a changepoint test, $supF_{\tau'}$, for intercept shifts over the middle (70%) observations of the sample, $\tau_{15\%} < \tau' < \tau_{85\%}$.[24] After obtaining the median-unbiased estimate of the transition variance, the remaining parameters, such as the time-varying intercept and fixed slope coefficients, are estimated by recursive filtering and smoothing equations, vid. Durbin and Koopman (2001).

Although means and sampling errors are estimated for the remaining regression coefficients, $\bar{\beta}_i, i = 2, \ldots, k$, the fixed partition of the random walk intercept is the initial condition, $\beta_{1,t_0} = \bar{\beta}_1$. To provide an approximate comparison with estimates of mean coefficients from alternative specifications, the finite sample average of the random walk intercept estimates is reported as the estimated mean, $\hat{\bar{\beta}}_1 \equiv \frac{1}{T_q}\sum_{t=1}^{T_q}\hat{\beta}_{1,t}$, along with the estimated standard deviation of this finite sample average.[25]

random walk coefficients (RWC)

In the examples of autoregressions, equation (18), or responses to gaps, equation (17), recovery of the natural rate requires transforming the estimated intercept by one or more slope coefficients of regressors. Depending on the scales of regressors, even modest variations in slope coefficients can imply large changes in natural rates. To allow for the possibility of economically meaningful variations in slope coefficients, the second approach extends the random walk specification to the slope coefficients of regressors, $\beta_{k,t}, k = 2, \ldots, \tilde{k}$.[26]

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[23] Applications that employ random walk intercepts to estimate a time-varying natural rate for unemployment include Staiger, Stock and Watson (1997), Gordon (1997), and Orphanides and Williams (2002). Time-varying intercepts have also been applied to estimation of the natural rate of the real interest rate, such as Laubach and Williams (2002), Kozicki (2004), and Clark and Kozicki (2004).

[24] Following Stock and Watson (1998), $\nu = \frac{\lambda}{T}$, where the probability of a zero pileup by maximum likelihood moves inversely with the local-to-zero parameter, λ, vid. Stock and Watson (1998, Table 1).

[25] For the random walk specification, $b_t = b_{t-1} + e_t$, denote the sample average as, $\bar{b} = \frac{1}{T_q}\sum_{t=1}^{T_q} b_t$. For a known initial condition, b_0, the variance of the sample average is $\sigma^2_{\bar{b}} = \frac{1}{T_q^2}\sum_{i=1}^{T_q} i^2\sigma^2_e = \frac{2T_q^2+3T_q+1}{6T_q}\sigma^2_e$, which can be large in lengthy samples.

[26] Three-variable vector autoregressions with random walk parameters are solved for "core" inflation and the natural rate of

Estimation is similar to that for the random walk intercept case, with appropriate modifications for the larger dimension of the $\tilde{\beta}_t$ vector. The transition matrix is an identity matrix, $\tilde{\Phi} = I_{\tilde{k}}$. Following Boivin (2004), the $\tilde{k} \times \tilde{k}$ variance matrix of the transition shocks is pre-estimated using a median-unbiased estimator, $\tilde{Q} = (\hat{\nu})^2(\frac{1}{T}\tilde{X}'\tilde{X})^{-1}\Omega(\frac{1}{T}\tilde{X}'\tilde{X})^{-1}$ where $\tilde{X}$ denotes the full sample column stack of $\tilde{X}_t$. As the format of potential heteroscedasticity in the residuals due to time-varying coefficients is not known prior to model estimation, a heteroscedasticity-consistent estimator is used, $\Omega = \frac{1}{T}\tilde{X}'D\tilde{X}$, where the nonzero elements of the $T \times T$ diagonal matrix are: $D_{\tau,\tau} = \frac{T}{T-\tilde{k}}\hat{u}_\tau^2$. Once again, ν is determined by the $supF_{\tau'}$ test statistic but here the test is formulated for shifts in $\tilde{k}$ elements of the coefficient vector, $\bar{\beta}$.

stationary coefficients (SC)

There are several pragmatic advantages of a random walk parameter specification, including parsimonious identification of the transition matrix, $\tilde{\Phi}$. However, this is only a tractable approximation with possibly unrealistic implications for model parameters and some natural rate constructions, such as $\bar{u}_t$ and $\bar{\pi}_t$, especially in lengthy samples.[27] If the evolution of empirical macro models is broadly viewed as an example of statistical learning of stable underlying relationships, it seems reasonable to allow for the possibility that model parameters may be approximated by autoregressions about a central tendency.

Principal differences in the stationary coefficient specification are that both the transition matrix, $\tilde{\Phi}$, and the covariance matrix of transition shocks, $\tilde{Q}$, are estimated by maximum likelihood.[28] Access to maximum likelihood estimation also permits likelihood tests of competing specifications with stationary coefficients.

Finally, in evaluating effects of stochastic parameter variation, it is useful to gauge the relative economic importance of estimated movements in a parameter. Graphs of the estimated trajectories of slope coefficients are not always informative because, as noted earlier, the effective contributions of slope parameters depend on regressor scales. In the case of stationary parameters, the steady-state variance of the dependent variable due to variation in β is

$$\text{var}(y) \quad = \quad \tilde{X}V(\beta)\tilde{X}',$$

where elements of the $\tilde{k} \times \tilde{k}$ steady-state covariance of the stationary parameters, $V(\beta)$, can be recovered from the column stack

$$\text{vec}V(\beta) \quad = \quad [I_{\tilde{k}^2} - \tilde{\Phi} \otimes \tilde{\Phi}]^{-1}\text{vec}\tilde{Q}.$$

unemployment in Cogley and Sargent (2003).

[27] Postwar aggregate unemployment and inflation rates in the US have remained within relatively narrow ranges, and empirical tests supporting unit root behavior appear to be sensitive to the choice of sample.

[28] To initialize maximum likelihood estimation in the stationary coefficients specification, each diagonal element of $\tilde{\Phi}_0$ is set to .8 and $\tilde{Q}_0$ is set to the median-unbiased estimator used in the random walk coefficients estimator.

In tables of subsequent sections, a variance decomposition is reported for the stationary coefficient specification[29]

$$\text{vardecom}(\beta_j) \quad \equiv \quad \frac{100}{\text{var}(y)}[\tilde{X}_j^2 V_{jj} + \frac{1}{2}\sum_{i \neq j} \tilde{X}_i \tilde{X}_j V_{ij}]. \tag{25}$$

3 Estimates of the natural rate for unemployment

This section briefly reviews several influential estimates of the natural rate of unemployment and inferences drawn from these constructions. These are compared with alternative estimates of $\bar{u}_t$ based on historical Greenbook forecasts using tvp regression models. Estimates of the unemployment natural rate from tvp autoregressions are not generally lower than retrospective estimates, whereas natural rate estimates from tvp structural equations are sensitive to dynamic specifications.

3.1 *Representative estimates of the natural rate of unemployment*

A real-time estimate of the quarterly unemployment rate, u_t, and several estimates of the natural rate for unemployment, $\bar{u}_t$, are charted in Figure 2.[30] Alternative natural rate estimates based on retrospective samples of historical data are represented by Staiger, Stock and Watson (1997)[31] and the Congressional Budget Office (2004). Both peak in the 1970s, with the CBO estimates averaging a half-point below the Staiger et al. estimates over the twenty-year sample shown.

As shown in the figure, there is much less agreement among real-time estimates of the behavior of the natural rate in the 1970s. The HP filter estimate is applied to the real-time estimates of the unemployment rate, and rises from about 4% to the level of the Staiger et al. retrospective estimate by the mid-1970s.[32] The smoother short series ending in 1976 is from Perry (1977). The remaining short series, ending in 1972, 1975, 1976, and 1978, are estimates of the natural rate of unemployment obtained by reverse engineering

[29] Equation (25) assigns half of the covariance, V_{ij}, to β_i and β_j, following Swamy and Tinsley (1980). Consequently, some elements of the variance decomposition may be negative under this convention.

[30] Annual dates on the horizontal axis denote the start of a year. As with other real-time estimates of historical variables used in this paper, the real-time estimate of the unemployment rate in period t, u_t, is drawn from the last Greenbook of the second following quarter, $t + 2$.

[31] Interpolated from first-quarter estimates provided on http://www.wws.princeton.edu/ mwatson/.

[32] The smoothing parameter for the filter of quarterly observations is 1600. Of course, the two-sided HP filter uses forward information not accessible in real time.

the real-time output gaps in Orphanides (2003a) using Okun's Law.[33]

These real-time estimates of the natural rate for unemployment support the view that monetary policy could have mistakenly eased in the 1970s, but with considerable variation in the size of the implied errors. Using the CBO retrospective estimate as an estimate of the "true" natural rate, underestimates of the natural rate range from 3%, for the real-time estimates ending in 1976, to 1%, for the real-time estimates ending in 1978. However, the output gaps used in the reverse engineering undoubtedly reflect also real-time errors in measuring GNP. The conventional view of the natural rate for unemployment in the 1960s was 4% so an upper bound for natural rate errors in the first-half of the 1970s is about 2%. Assuming Perry (1977) represents a conventional estimate of the natural rate by the mid-1970s, an upper bound for underestimates in the second-half of the 1970s is 1%. This suggests that if the FOMC had been using a stable Taylor rule, as empirically supported by Orphanides (2001), errors in estimating the natural rate of unemployment could have mistakenly reduced the policy rate by 100 to 200 basis points.[34]

As noted earlier, standard models for predicting inflation in the 1970s were variations of a Phillips curve with the unemployment gap, $u_t - \bar{u}_t$, as an explanatory regressor. Romer and Romer (2002) have suggested that the "very low estimates of normal unemployment that characterized the economic beliefs of policymakers in the 1960s and 1970s would naturally tend to lead policymakers to systematically underpredict inflation." A priori, this might seem unlikely as judgemental specialists are adept at using "add factors" to adjust for systematic biases in forecast errors. The forecast errors of Greenbook current-quarter predictions of GNP inflation are charted in Figure 3. [35] The mean of the inflation prediction errors is near zero, 0.02%, over a 1969Q1 - 1997Q2 sample. The largest inflation underpredictions in the 1970s follow crude oil price shocks in 1973-4 but precede oil shocks in 1979-80. The mean prediction error is positive, 0.83%, in the first-half of the 1970s but negative, -0.14%, in the second-half. If the inflation-bias conjecture is correct, a reduction in the measurement error of the natural rate of unemployment might explain the smaller inflation forecast errors in the last-half of the 1970s. Romer and Romer suggest -.125 as an estimate of the slope of the Phillips curve. Assuming the measurement error of conventional estimates of $\bar{u}$ fell by

[33]We are indebted to Athanasios Orphanides for supplying the real-time output gap data. The estimates in Figure 2 are obtained by $\bar{u}_t = u_t - \frac{1}{a'}(y_t - \bar{y}_t)$, using an Okun's Law coefficient of $a' = 2.2$. Although Okun (1962) initially suggested estimates of a' around 3.2, Tatom (1978) indicates an estimate around 2.2 is consistent with 1955Q1-1969Q4 and 1955Q1-1977Q3 samples.

[34]An Okun's Law coefficient of around two implies the coefficient of a Taylor rule response to the unemployment gap is one. By contrast, Orphanides (2001, Figure 4; 2003a, Figure 5) suggests shortfalls of the funds rate, due to central bank real-time measurement errors, approach 600 basis points during intervals in the 1970s.

[35]Current-quarter prediction errors of real-time inflation measurements are measured by the average of the forecast error of the last Greenbook in the current quarter, t and in the preceding quarter, $t-1$.

one percentage point in the 1970s, as suggested above, this would explain only 13% of the net reversal of the mean forecast error of inflation in the first and second halves of the 1970s.

However, Romer and Romer (2002) do not rely on conventional estimates of $\bar{u}_t$, and present an innovative use of Greenbook forecasts to support their position that the central bank made large errors in measuring the natural rate of unemployment. Their constructions are based on inverting a standard "accelerationist" Phillips curve to give

$$\hat{\bar{u}}_t = \frac{1}{3}\sum_{h=0}^{2}(u_{t+h} + \frac{1}{.125}\Delta\pi_{t+h}), \tag{26}$$

where, using our earlier notation, all variables on the rhs of (26) are forecasts from the Greenbook in t. Even though these constructions use averages of the three initial forecasts in the Greenbook forecast horizon, $h = 0, 1, 2$, the estimates of $\bar{u}_t$ are quite volatile over time. Romer and Romer (2002) list averages over subperiods, which are reproduced in the second column of Table 1. When contrasted with the CBO estimates of $\bar{u}$ in the first column of the table, these estimates suggest a more dramatic interpretation of central bank perceptions in the 1970s. In contrast to the underestimation by conventional estimates of $\bar{u}$ of about 2 percentage points in the first-half and 1 percentage point in the second-half of the 1970s, the Romer and Romer estimates imply the natural rate estimates implicit in Greenbook forecasts underestimated $\bar{u}_t$ by nearly 3 percentage points in the first-half, and overestimated by 0.9 percentage points in the subsequent sixteen quarters ending with the Miller tenure, a swing of nearly 4 percentage points in Greenbook revisions of the natural rate for unemployment.

3.2 *Implicit Greenbook estimates of $\bar{u}_t$ from tvp autoregressions*

Atheoretic estimates of natural rates of unemployment implied by Greenbook forecasts are provided by fourth-order autoregressions, as shown earlier in equation (18).

$$u_{t+h} = \beta_{1,t} + \beta_{2,t}u_{t+h-1} + \sum_{j=2}^{4}\beta_{j+1,t}\Delta u_{t+h-j+1} + a_{t+h}, \tag{27}$$

In the applications summarized in the top panel of Table 2, the tvp autoregression is fit to the multiperiod forecasts of all 315 Greenbooks in the 1966Q3 - 1997Q4 sample, a total of 1784 observations.[36] After examining a number of tvp applications, our experience is that the means of the time-varying coefficients,

[36] Change-point tests for the unemployment autoregression imply $\lambda = 16.2$. For this level of the local-to-zero parameter, Table 1 in Stock and Watson (1998) suggests the probability of a zero pileup by maximum likelihood is less than 13%.

the maximum and minimum of the implied natural rates, and the variance decompositions provide useful summary contrasts among alternative specifications. Where relevant, these statistics are shown for the three tvp specifications: the random walk intercept (RWI) model; the random walk coefficients (RWC) format; and the stationary coefficients (SC) specification.

Both mean coefficients and bounds of the natural rates are similar across the three tvp specifications in the top panel of Table 2. This is born out in Figure 4, which shows that the natural rates of the three specifications move closely together. The 70% confidence interval shown is for the stationary coefficients specification.[37] This interval is large, containing not only all three tvp specifications, but also the HP filter and CBO estimates of the natural rate for most of the sample. The SC autoregression remains stable throughout the sample, with the coefficient of the lagged level, $\beta_{2,t}$, remaining well below unity. Some of the remaining slope coefficients were rather volatile, such as $\beta_{3,t}$ which oscillated between values of .07 to .77 over the sample. However, the unemployment effects of these movements are not necessarily quantitatively important. A more informative measurement is the variance decomposition shown in the last line of the top panel of Table 2. This decomposition shows that the largest stochastic unemployment effects are those associated with movements in the two determinants of the natural rate: the intercept, $\beta_{1,t}$, and the coefficient of the lagged level, $\beta_{2,t}$.

An interesting property of the tvp natural rates shown in Figure 4 is that turning points of these constructions tend to lead those of the two-sided HP filter estimate, whose turning points are coincident with those of the real-time unemployment rate. This suggests that conventional estimators of natural rates, fit to historical data, may significantly underestimate the ability of judgemental forecasters to anticipate movements in natural rates.[38] One difference is that the tvp estimators used here are fit to multiperiod forecasts of future activity.

A second feature of the tvp natural rate estimates in Figure 4 is that they are almost as volatile as the HP filter estimate. One reason is that forecasts in the initial quarters of the forecast horizon, say $h = 0, 1$, are often heavily adjusted by judgemental "add factors" to take account of information that is not contained in Greenbook records, such as high-frequency data releases or judgement about the persistence of recent forecast errors.[39] This is less of a problem for more distant autoregressive forecasts in the forecast horizon

[37]The confidence interval of the natural rate is constructed by the delta method, using smoothed estimates of the covariance matrices of the coefficient vector, β_t.

[38]In analyses of incomplete or asymmetric information, statistical learning models generally impose lengthy learning lags.

[39]Although the term "add factors" suggests intercept corrections, judgemental adjustments may also reflect time-varying weights

because the influence of transient add factors dissipate and, by construction, persistent adjustments of the forecast are captured in the forward forecast regressors that replace lagged real-time measurements of past behavior as h advances.

To reduce the influence of transient adjustments in initial quarters of the forecast horizon on estimated natural rates, the lower panel in Table 2 reports the results of tvp autoregressions where the first three forecasts in a Greenbook, $h = 0, 1, 2$, are dropped from the sample. As can be seen from the earlier charting of forecast horizons in Figure 1, this requires dropping Greenbooks with short forecast horizons, $H_{t_g} < 3$, from the sample. To provide a sample with contiguous quarters, the sample span is now the 116 quarters from 1969Q1 to 1997Q4, containing 261 Greenbooks. The total number of observations for forecasts that contain the fourth quarter of the forecast horizon or later, $h \geq 3$, is 879, a reduction of about 50%.

Differences in the tvp estimators of the shorter stack of forecasts are evident in the lower panel of Table 2. The bounds of the natural rate constructions are closer together, indicating that the shorter stack reduces the influence of transient judgemental forecast adjustments. Reduced effects of idiosyncratic add factors are also evident in the variance decomposition of the stationary coefficients estimator, where the relative importance of intercept variations has been reduced by nearly 60%. Although not shown, the unemployment natural rate implied by the reduced stack of Greenbook forecasts is smoother and less subject to large amplitude movements than the natural rate constructions implied by the full stack of forecasts shown in Figure 4. However, as indicated in Table 1, the natural rate constructions of either of the SC autoregressions do not support the substantial underestimates of $\bar{u}_t$ in the 1970s reported by Romer and Romer (2002).

3.3 *Implicit Greenbook estimates of $\bar{u}_t$ from tvp structural specifications*

This subsection explores time-varying natural rates of unemployment implied by tvp estimators of aggregate pricing equations. To reduce distortions associated with near-term judgemental add factors, the short stack of forecasts is used in estimation, where $h_{t_g} = 3, \ldots, H_{t_g}$.[40]

backward-looking specifications

The equation described in the top panel of Table 3 is the same as the Romer and Romer specification noted in equation (26), except that the mean slope of the Phillips equation, $\bar{\beta}_2$, is freely estimated and, in the case of the RWC and SC specifications, both the intercept and slope coefficients can vary over time. The

placed on competing models. Use of disparate information sources in the Greenbook forecast is discussed in Kalchbrenner and Tinsley (1977).

[40]For comparability, all tvp structural pricing equations use the local-to-zero parameter: $\lambda = 8.6$.

backward-looking equation described in the bottom panel relaxes the assumption that expected inflation is a random walk and uses an autoregressive predictor, but maintains the assumption that there is no long-run tradeoff between inflation and unemployment.[41] The mean coefficient, $\hat{\beta}_3$, of the additional lag in inflation, π_{t+h-2}, is significant with zero p-values in both the RWI and SC specifications.

Both panels of Table 3 indicate that the Romer and Romer restriction on the mean slope of the pricing equation, $\bar{\beta}_2 = -.125$, is contained within 95% confidence intervals. However, this masks large sample movements in the time-varying estimates of $\beta_{2,t}$. Evidence of this movement is seen in the variance decompositions of both panels, where movements in the slope parameter dominate the variance of the unemployment rate. Although not shown, both the RWC and SC estimates of $\beta_{2,t}$ remain around -.10 in the 1970s and then rise sharply and level off around -.05 by 1984. The sizeable reduction in the slope of the pricing equation after 1979 was a major contributor to the average increase of about 1 percentage point in estimates of the natural rate of unemployment.

As shown in Table 5, both of the backward-looking specifications of the pricing equation support an underestimation of the natural rate for unemployment in the Greenbooks of the 1970s, with $\bar{u}_t$ rising from 4% in the early Burns years, to around 4.5% in the Miller era, and to about 5.5% in the remainder of the sample. Because it exhibits the lowest values in the 1970s, the natural rate implied by the pricing equation with the autoregressive inflation predictor, denoted by $\bar{u}_t^b$, is a lower-bound estimate.

forward-looking specifications

A risk of theory-based specifications is that they may not capture the undocumented relationships used by Greenbook forecasters. Inspection of representative staff Phillips curves from the 1970s suggests that additional regressors usually included one or more lags in the first-difference of the unemployment rate and additional lags of inflation, e.g. Enzler and Pierce (1974). One parsimonious way to capture the forecast implications of additional regressors and unknown dynamic specifications is to include forecast leads of these variables.

The tvp estimators presented in the top panel of Table 4 use the forward-looking specification

$$\pi_{t+h} = \beta_{1,t} + \beta_{2,t} u_{t+h} + \beta_{4,t} \Delta u_{t+h+1} + \beta_{5,t} \pi_{t+h+1} + (1 - \beta_{5,t}) \pi_{t+h-1} + a_{t+h}, \qquad (28)$$

where $\beta_{4,t}$ captures forecasts of the forward change in unemployment, and $\beta_{5,t}$ is the weight on the forward

[41] According to Enzler and Pierce (1974), macro data samples after 1971 supported a unit sum for the estimated coefficients of lagged inflation in empirical Phillips curves.

forecast of inflation. Thus, this equation is similar to hybrid modifications of the NK pricing equation.

For all three tvp estimators in the top panel of Table 4, the mean coefficient of the unemployment rate, $\bar{\beta}_2$, is smaller in absolute value, indicating that the slope of the forward-looking Phillips curve is flatter than the backward-looking equations in Table 3. Although not shown, the coefficient of forward inflation, $\beta_{5,t}$, rises from around 0.4 in the early 1970s to around 0.6 in the mid-1980s, indicating more weight on the forward inflation regressor in the 1980s and 1990s. The largest slope coefficient movements are associated with the coefficient of the forward change in the unemployment rate, $\beta_{4,t}$, moving from negative values of around -.30 in the 1970s to positive values of around .15 by the mid-1980s. The zero crossing in 1984 also explains why the estimated mean, $\bar{\beta}_4$, is not significantly different from zero.[42]

Although the maximum and minimum bounds in Table 4 for the natural rate constructions of the RWI and SC equations are consistent with reasonable estimates of the unemployment natural rate, the bounds for the RWC estimator imply implausible values. The difference is due to the estimated behavior of the coefficient of the unemployment rate, $\beta_{2,t}$, in the random walk coefficients estimator, RWC, and in the stationary coefficients estimator, SC. As charted in Figure 5, the SC estimate rises towards zero, similar to the motion observed for this coefficient in the backward-looking equations. However, the RWC estimate of $\beta_{2,t}$ continues to climb and crosses zero in 1984, where the RWC equation cannot identify the unemployment natural rate. When $\beta_{2,t}$ is in the neighborhood of zero, the RWC specification generates very large positive and negative constructions of $\bar{u}_t$.

Using the stationary coefficients, SC, estimators for comparison, the lower bound for the natural rate of the backward-looking equation in the bottom panel of Table 3 is 3.8 whereas the lower bound for $\bar{u}_t$ in the forward-looking equation of the top panel of Table 4 is 5.5. The likelihood ratio of the two equations is 4.1, favoring the forward-looking specification. Assuming uniform priors across the two equations, one way to proceed would be to construct a weighted average of the two natural rate constructions, with approximate posterior weights of 0.8 on the forward-looking estimate and 0.2 on the backward-looking estimate.

As an alternative to fixed-weight averaging, suppose both the backward-looking and forward-looking models are considered by the judgemental forecaster in a given period, where the probability of choosing the forward-looking specification is α_t, and the probability of choosing the backward-looking specification is $1 - \alpha_t$. Estimates of the forecast model implied by this time-varying averaging are presented in the

[42]Note that the mean of a time-varying parameter can be zero and yet provide a significant contribution to the variation of the dependent variable. The variance decomposition indicates that this is not the case here but we have retained the first-difference of the unemployment rate because of the prior evidence that staff Phillips equations used this regressor.

bottom panel of Table 4. Although realizations of α_t are not identified, most of the mean coefficients of the combined equation move in directions consistent with the likelihood ratio. For example, the mean slope of the Phillips curve, $\bar{\beta}_2$, is closer to the mean slope of the forward-looking specification, and the mean coefficient on the lagged difference of inflation, $\bar{\beta}_3$, is about one-third the size of the mean estimate of the backward-looking specification. As with the forward-looking equation, the natural rate bounds implied by the RWC estimator are unrealistically large due to the same trending behavior in the estimate of $\beta_{2,t}$.

Subsample averages of the natural rates of unemployment, $\bar{u}_t$, implied by the equation with AR(2) inflation expectations and the equation with a tvp averaging of expectations are listed in the last two columns of Table 5. Both the equation with AR(2) inflation expectations, in the fourth column of Table 5, and the equation with tvp averaging, in the sixth column, indicate underestimation of the natural rate for unemployment, $\bar{u}_t$, in the 1970s, but the underestimates are quite modest in the tvp averaging equation.

Because the statistical evidence supports the tvp averaging equation, the remainder of the paper uses the stationary coefficients estimator of this equation as the preferred Greenbook estimate of the natural rate of unemployment, $\bar{u}_t$.

4 Historical policy responses and estimates of the natural rate for inflation

This section discusses implicit estimates of Greenbook forecasts for the natural rate for inflation, $\bar{\pi}_t$, from tvp autoregressions and tvp descriptions of policy response rules.

4.1 *Implicit Greenbook estimates of $\bar{\pi}_t$ from tvp autoregressions*

Similar to equation (27) for the unemployment rate, a fourth-order autoregression is fit for Greenbook forecasts of inflation

$$\pi_{t+h} = \beta_{1,t} + \beta_{2,t}\pi_{t+h-1} + \sum_{j=2}^{4} \beta_{j+1,t}\Delta\pi_{t+h-j+1} + a_{t+h}, \tag{29}$$

Summary statistics of the three tvp estimators of autoregressive models of Greenbook inflation forecasts are presented in Table 6.[43] The mean coefficients of all three estimators are similar. Also, despite the large relative variance contribution attributed to movements in the coefficient of the lagged level of inflation, $\beta_{2,t}$, the minimum and maximum bounds of the natural rate for inflation are well-behaved.

[43] These estimators use the shorter stack of Greenbook forecasts, which eliminates the first three quarters in the forecast horizon. The estimated local-to-zero parameter for the inflation autoregressions is $\lambda = 8.1$. Throughout this paper, quarterly inflation is measured at annualized rates.

The natural rates for inflation, $\bar{\pi}_t$, generated by the tvp estimators are contrasted with an HP filter of the real-time estimates of inflation in Figure 6. In contrast to the earlier lead of turning points in unemployment by the tvp autoregressive estimators of $\bar{u}_t$, as shown earlier in Figure 4, turning points in the natural rate of inflation, $\bar{\pi}_t$, implied by inflation tvp autoregressions appear to lag turning points in real-time inflation.

Like historical inflation, summarized by the smoothed HP filter, the autoregressive estimate of the natural rate $\bar{\pi}_t$ increases in the 1970s and eventually retraces its steps in the 1980s and 1990s, but with a considerable lag. The main reason for this lagged behavior is that the tvp autoregression is a reduced form representation of the time-varying structure of the Greenbook forecast model. Under asymmetric information, this model contains both the Greenbook estimate of the true policy target for inflation, $\bar{\pi}_t$, and the Greenbook estimate of the private sector perception of the inflation target, $\bar{\pi}_t^p$. Consequently, the autoregressive estimate of the natural rate is a time-varying average of the actual and perceived natural rates. Previous estimates of the private sector perception of the natural rate for inflation, such as Kozicki and Tinsley (2001a), indicate that $\bar{\pi}_t^p$ lags, considerably, the turning points of historical inflation.

Under asymmetric information, the private sector perception of the natural rate for inflation plays a major role in anchoring forward expectations of inflation, which appear in both the pricing equations of firms and the forward policy rate perceptions of traders in financial asset markets. Thus, in small structural macro models, the true central bank target for inflation explicitly appears only in the description of policy rate responses, such as equation (4). Consequently, estimation in the next subsection uses a policy response function to identify variation in the true policy target for inflation.

4.2 *Implicit Greenbook estimates of $\bar{\pi}_t$ from tvp policy response equations*

This section explores the following description of FOMC policy responses where, as noted earlier, the employment gap provides a plausible indicator of historical policy objectives regarding economic slack. In the absence of policy rate smoothing, the desired setting of the federal funds rate at the FOMC meeting in period t_f is the forward-looking specification

$$r^*_{t_f} \quad = \quad \bar{\rho}_t + \bar{\pi}_t + c_{2,t}(\pi^k_{t|t_g} - \bar{\pi}_t) + c_{3,t}(u_{t+k|t_g} - \bar{u}_t) + c_{4,t}\Delta u_{t|t_g}. \tag{30}$$

Both the date of the relevant Greenbook forecast, t_g, and the date of the FOMC meeting, $t_f > t_g$, are contained in the current quarter, t. The inflation and unemployment regressors on the rhs of equation (30) are drawn from the Greenbook in period t_g. The inflation measure, $\pi^k_{t|t_g}$, is an average of forecasts up to quarter $t + k$ in the forecast horizon and may also include Greenbook estimates of recent inflation, and $u_{t+k|t_g}$ is the Greenbook forecast of the unemployment rate in quarter $t + k$. The desired policy rate may also be a function of the projected change in the unemployment rate, $\Delta u_{t|t_g}$. This addition approximately nests a number of alternative specifications of FOMC policy responses.[44]

Dynamic adjustments of the funds rate are represented by

$$r_{t_f} = (1 - \beta_{6,t})r^*_{t_f} + \beta_{5,t}\Delta r_{t_f-1} + \beta_{6,t}r_{t_f-1} + a_{t_f}, \tag{31}$$

which contains a partial adjustment of the funds rate level to the desired setting and a term capturing any continuation of the policy rate change selected in the last Greenbook. Combining equations (30) and (31) gives

$$\begin{aligned} r_{t_f} &= \beta_{1,t} + \beta_{2,t}\pi^k_{t|t_g} + \beta_{3,t}(u_{t+k|t_g} - \bar{u}_{t|t_g}) + \beta_{4,t}\Delta u_{t|t_g} \\ &\quad + \beta_{5,t}\Delta r_{t_f-1} + \beta_{6,t}(r_{t_f-1} - \bar{\rho}_t) + \bar{\rho}_t + a_{t_f}, \end{aligned} \tag{32}$$

To identify the natural rate of inflation, implied Greenbook constructions from the previous section are used as estimates of the natural rate for unemployment, $\bar{u}_t$. The natural rate of the real policy rate, $\bar{\rho}_t$, is approximated by an HP filter of the historical funds rate less the Greenbook forecast of inflation, $r - \pi$.[45] Under these assumptions, the natural rate of inflation implied by equation (32) is $\bar{\pi}_t = -\beta_{1,t}/(\beta_{2,t}+\beta_{6,t}-1)$.

The policy rate on the lhs of equation (32) is the average of federal funds rates in the interval following the FOMC meeting in t_f to the next meeting in $t_f + 1$. The lagged policy rate regressor, r_{t_f-1}, is the average funds rate since the previous FOMC meeting.[46] As noted previously, column stacks of expected future funds rates are not feasible because Greenbook forecast assumptions about future policy rates over the forecast horizon are not publically available. To facilitate some smoothing of natural rate estimates, data associated with Greenbook dates falling in the same quarter, t, are stacked in the observation vectors and matrices, y_t and X_t. To simplify subscript notation, the FOMC and Greenbook conditioning dates, t_f and t_g, are generally suppressed in the remaining discussion.

As shown in Figure 1, the horizon of forward expectations, k, is limited in early years of the sample. The policy equation using a two-quarter lead, $k = 1$, is estimated by the three tvp estimators over a 1969Q1

[44] Judd and Rudebusch (1998) and Lansing (2002) suggest FOMC policies after the 1970s placed a greater emphasis on the change in output.

[45] The average of the natural rate construction is 2.6 over the full sample, with $\bar{\rho}_t$ falling below the average value in the mid-1970s and rising above the average in the first half of the 1980s.

[46] As FOMC dates are not evenly spaced over the calendar, the number of days in the funds rate averages will vary but the tvp specification may partially compensate for this. Fixed-coefficient regressions of meeting-to-meeting adjustments of the funds are explored in Froyen and Waud (2002).

- 1997Q4 sample containing 280 Greenbooks.[47] The tvp estimators accommodate two shifts in the variance of the measurement error, σ_a, to account for the change in operating procedures from 1979Q4 to 1982Q3.[48]

The top panel of Table 7 uses $\bar{u}_t$, the natural rate of unemployment estimated by the pricing equation with tvp averaging, and the bottom panel uses $\bar{u}_t^b$, the natural rate of unemployment from the pricing equation with AR(2) inflation expectations. In both panels, the maximum and minimum bounds of the implied natural rate for inflation, $\bar{\pi}_t$, are large, suggesting difficulty in identifying $\bar{\pi}_t$ over part of the sample. The variance decomposition indicates a substantial source of stochastic variation in the policy rate is due to time-varying movements in the response to inflation, $\beta_{2,t}$. This suggests that movements in the policy response to inflation may be contributing to the implausible movements of the estimated natural rate for inflation.

Estimates of the long-run policy responses to inflation, $c_{2,t}$, from the RWC and SC estimators in the top panel of table 7 are charted in Figure 7. Although the long-run response appears to be greater than one for much of the sample, large estimates of the natural rate for inflation, $\bar{\pi}_t$, occur when $c_{2,t}$ enters the neighborhood of unity. As shown in Figure 7, there are two unit crossings by $c_{2,t}$ in the 1970s for the SC estimator and an additional crossing in the 1990s for the RWC estimator.[49]

Previous studies, such as Orphanides (2001), have suggested that the policy response equation exhibits stable responses to inflation, $c_2 > 1$, when real-time estimates of the natural rate of output are used in the policy regression. The lower panel of Table 7 uses the natural rate of unemployment, $\bar{u}_t^b$, that represents the upper bound on real-time measurement errors in the Greenbook forecasts. This substitution generally increases the bounds of the implied natural rate for inflation. The reason for this additional deterioration is that the long-run responses to inflation, $c_{2,t}$, for the RWC and SC tvp estimators in the lower panel are generally smaller than those in the top panel and not only reproduce the unit crossings of the top panel but also remain in the neighborhood of unity from the mid-1970s to the mid-1980s.

Tests for structural changes in the coefficients of the policy equation indicate a major shift at the end of the 1970s.[50] As the alternative construction of the natural rate for unemployment, $\bar{u}_t^b$, is not sufficient to

[47]The Greenbook of November 15, 1972 contains only a current quarter forecast, $H = 0$. For this Greenbook, the current quarter forecast is repeated when a two-quarter forecast horizon is required, as for $k = 1$.

[48]The use of a nonborrowed reserves instrument during the 1979-82 interval increased the effective variance of a_t by introducing shocks from money demand and the banking reserves market, vid.Tinsley, von zur Muehlen,and Fries (1982). For the FOMC policy response rule, a mid-sample changepoint test estimates the local-to-zero parameter as $\lambda = 11.1$.

[49]In the case of the fixed slope estimator, RWI, in the top panel, $\bar{c}_2$ is slightly below one, and the natural rate of inflation is obtained by scaling the time-varying intercept by 333.3.

[50]The test statistics are robust to residual heteroscedasticity. The largest test statistics occur in early 1980 with zero p-values, using the tables in Hansen (1997).

explain the policy transition, the remainder of this section explores estimations of separate policy responses for the Burns/Miller era and the Volcker/Greenspan tenures.

Policy during the Burns/Miller tenures

Results of fitting equation (32) to Greenbook forecasts in the Burns/Miller era are presented in the top panel of Table 8. The policy regime, 1970Q1 through 1979Q2, spans 38 quarters and 115 Greenbooks. Although the bounds of the natural rate for inflation are better behaved for the random walk intercept (RWI) estimator, the bounds remain implausibly large for the two estimators with time-varying slopes, RWC and SC. Also, in contrast to fixed coefficient regression studies of US policy responses in the 1970s, the mean responses to inflation and measures of real economic activity are insignificant, with p-values around 0.40 for the response to the unemployment gap and around 0.25 for the response to the change in unemployment.[51]

Fixed coefficient regression studies of US monetary policy generally indicate that policy in the 1970s responded significantly to gap measures of real activity.[52] In exploring this suggestion, the second panel in Table 9 drops the unemployment change regressor and the third panel eliminates the unemployment gap regressor. Interestingly, the distance between the maximum and minimum bounds of the natural rate of inflation remain within single digits for all three estimators of the third panel in Table 8, where the unemployment gap regressor is eliminated. However, mean responses to both the forecast inflation gap, $\bar{\beta}_2$, and the unemployment difference, $\bar{\beta}_4$, remain statistically insignificant.

To check the robustness of the apparent statistical insignificance of the mean response to inflation, a four-quarter average of inflation is introduced in Table 9. The inflation regressor is now averaged over Greenbook real-time estimates of inflation in the two previous quarters, $h = -2, -1$, in addition to forecasts of inflation in the next two quarters, $\pi_t^k \equiv \frac{1}{4} \sum_{h=-2}^{1} \pi_{t+h}$. As both recent measurements and forecasts of inflation can be subject to sizeable revisions over time, it seems plausible that FOMC members may differ in the emphasis placed on forecasts or recent measurements in weighing their policy decisions.

In the top panel of Table 9, mean responses to both inflation and the first-difference of unemployment are statistically significant. The mean response to the unemployment gap, $u_{t+1} - \bar{u}_t$, is marginally significant, with a p-value of .09, for the RWI estimator and insignificant for the SC estimator. The lower bounds for the implied natural rate of inflation are negative for all three tvp estimators.

[51]Examining the significance of the mean policy responses to inflation and the two unemployment measures are meaningful as there are no zero crossings by the tvp coefficients on these regressors in the remaining sections of the paper.

[52]Significant mean responses to output gaps in the 1970s are reported in Judd and Rudebusch (1998), Taylor (1999), Clarida, Gali, and Gertler (2000), Orphanides (2001), and Nelson (2004).

When the first-difference of the unemployment rate is dropped as a regressor, in the middle panel of Table 9, mean policy responses to the unemployment gap, $\bar{\beta}_3$, are insignificant, with p-values around .20. By contrast, mean policy responses to the first-difference of the unemployment rate in the bottom panel of Table 9 are significant, as are the mean responses to inflation.[53]

In all three panels of Table 9, the upper bounds for the implied natural rate of inflation, $\bar{\pi}_t$, are large for the random walk coefficients estimator, RWC. The principal reason is that the estimated long-run response to inflation, $c_{2,t}$, either remains in the neighborhood of unity or exhibits a unit crossing. Figure 8 charts estimates of $c_{2,t}$ for the three tvp policy rules of the bottom panel in Table 9. The long-run policy response to inflation remains below unity for both the RWI and SC policy equations, but $c_{2,t}$ has a unit crossing in 1972 for the RWC policy equation. In addition, the estimated long-run response to inflation falls in 1974 for both the RWC and SC equations.

Recalling the two leading interpretations of US policy in the 1970s, the evidence of the tvp estimators presented in this section supports the passive policy interpretation. Indeed, the natural rate error explanation appears to be largely irrelevant, as there is little empirical support for a systematic policy response to the unemployment gap.[54] An alternative interpretation of US policy in the 1970s is explored in section 5.

Policy during the Volcker/Greenspan tenures

The policy equation (32) is estimated for the Volcker/Greenspan policy era, 1979Q3 through 1997Q4, a span of 75 quarters and 152 Greenbooks.[55] Estimates of the three tvp specifications are summarized in Table 10.

The construction of the inflation regressor, π_t^k, varies in each of the three panels of Table 10. Inflation is averaged over the first two quarters of the Greenbook horizon in the top panel, $h = 0, 1$. The inflation regressor is extended to a four-quarter average in the middle panel, $h = -2, -1, 0, 1$. Finally, given the availability of longer Greenbook forecast horizons in the Volcker/Greenspan sample, the four-quarter inflation average is shifted ahead by two quarters in the bottom panel, $h = 0, 1, 2, 3$.

[53]In addition to the statistical insignificance of mean policy responses to the unemployment gap, $\bar{\beta}_3$, a Chi-squared test of the likelihoods of the SC equations in the top and bottom panels of Table 9 does not reject zero restrictions on the additional parameters required for a tvp policy response to the unemployment gap.

[54]The absence of a policy response to unemployment gaps also casts doubt on interpretations of 1970s US monetary policy based on a difference between the natural rate of unemployment and a central bank target for unemployment, such as posited in the time inconsistency literature or the central bank misperception analysis of Sargent, Williams, and Zha (2004).

[55]Fixed-coefficient residuals, u_t, exhibit less volatility in the Volcker/Greenspan sample than in the Burns/Miller sample. The estimate of the local-to-zero parameter for the Volcker/Greenspan sample is lowered to $\lambda = 6.9$, a result consistent with a mid-sample changepoint test for the Volcker/Greenspan observations. Estimated outcomes in the Burns/Miller sample, such as statistical insignificance of mean policy responses to the unemployment gap, are maintained if the lower local-to-zero parameter is used also for the 1970s.

The estimated mean policy responses to all regressors, including both the unemployment gap and the first-difference in unemployment, are generally statistically significant in all three panels of table 10. The lower bound of the natural rate for inflation, $\bar{\pi}_t$, is negative for all tvp specifications in the top panel and for the random walk coefficients, RWC, equations in all three panels. As with the policy equations estimated for the Burns/Miller sample, these negative bounds are due to unit crossings of the estimated long-run policy response to inflation, $c_{2,t}$. Figure 9 displays estimates of the policy response to inflation for the three tvp estimators of the middle panel. The $c_{2,t}$ response estimate by the SC equation is smaller in the early 1990s but remains above one throughout the sample, whereas the response by the random walk coefficients, RWC, equation continues to drop and falls below one in 1994.

The estimated characteristics of the stationary coefficients estimator, SC, are similar in the middle and bottom panels of Table 10. A likelihood ratio suggests a slight advantage for the specification in the middle panel where the four-quarter average of inflation, π_t^k, contains both forward forecasts and backward real-time estimates, $h = -2, -1, 0, 1$.[56] The time profile of the natural rate for inflation, $\bar{\pi}_t$, in the Volcker/Greenspan sample that is implied by the SC equation in the middle panel is presented in Figure 10. The remaining variables in Figure 10 are discussed in the next section.

5 An alternative interpretation of policy in the 1970s

"If you can remember anything about the sixties (and seventies), you weren't really there" - Paul Kantner

Simple policy response equations that relate movements of the policy interest rate, r, to changes in arguments of the central bank preference function, such as inflation, π, and real economic activity, y or Δy, are the basis of many useful empirical descriptions of historical monetary policy. However, positing a direct link between the policy instrument and ultimate policy objectives conceals a major flaw in the design of monetary policy in the 1970s. This section indicates that intermediate targeting of monetary aggregates–a monetarist strategy that dominated FOMC policy in the 1970s–provides a unified interpretation of the Great Inflation, explaining the irrelevance of the natural rate error interpretation and providing a more historically accurate description of policy design in the 1970s.

The gathering influence of monetarism on US monetary policy

In a collection of highly influential essays, Friedman (1960) indicated that "I share the doubts that the Federal

[56] Several papers demonstrate that indeterminacy may occur if policy responds to arguments in distant forecasts; see the excellent numerical analysis in Batini and Pearlman (2002).

Reserve has repeatedly expressed about the desirability of using price level stability as an intermediate guide to policy." Instead, he proposed that the central bank pursue constant growth of the money stock. In 1960, a unified measure of the money supply was published in the October Federal Reserve *Bulletin*. In the June 1966 FOMC meeting, the FOMC Policy Directive to the trading desk of the Federal Reserve Bank of New York contained the first "proviso" reference to the required reserves aggregate as a secondary target. Finally, in the second FOMC meeting chaired by Arthur Burns, the Policy Directive adopted at the March 10, 1970 meeting selected the growth of monetary aggregates as principal targets of US monetary policy.

Policy forecasting and FOMC policy discussions in the 1970s were shaped by the two-stage design that is characteristic of intermediate targeting. Greenbook forecasts of economic activity were conditioned on the assumption of a trajectory for the money supply over the forecast horizon, vid. Kalchbrenner and Tinsley (1977).[57] As noted earlier, to assist sectoral specialists, the senior staff translated the money supply assumption into staff expectations of bond yields over the forecast horizon.

By contrast, short-run policy options were formulated as competing money growth paths associated with alternative settings of the policy instrument, usually the funds rate. In principle, the competing options for the money supply represented different short-run paths toward the baseline money supply trajectory assumed in the Greenbook. These short-run policy options were presented in the Blue Book. Each Blue Book contained a brief summary of recent activity in money and banking markets and suggested, generally, three policy options for discussion by the FOMC.[58] Forecasts of money growth associated with alternative policy rate settings appear in the Blue Book presented at the first FOMC meeting chaired by Arthur Burns on February 10, 1970. Although alternative forecasts of the money supply were initially limited to the current

[57]Generally, the monetary policy assumption of the Greenbook forecast was the M_1 growth rate target selected at the last FOMC meeting. For example: "That growth rate of money (4%) had been assumed for projection purposes because the Committee had been employing such a rate as a target over the past several months." Partee, FOMC Economist (MOD, 6/23/70, p.31); and "In developing our base projection, which is laid out in detail in the green book, we have adopted several policy assumptions. The monetary policy assumption calls for a continuation of the present policy stance through 1976, as indexed by the growth in the narrow money supply at around the 6-1/4 per cent midpoint of the range that has been announced by the Committee." Partee (MOD 6/16/75, p.4).

[58]Two examples of staff interpretations of the Bluebook policy options are: "Mr. Axilrod observed that among the alternative sets of relationships between monetary aggregates and money market conditions presented in each blue book, there was always one that represented a continuation of the Committee's current longer-run target for the aggregates. There was always another alternative that represented a continuation of prevailing money market conditions." (MOD, 11/20/72, p.52); and "Mr. Partee said it might be helpful if he explained how the staff proceeded in formulating the blue book alternatives. One of the alternatives always shown involved the maintenance of prevailing money market conditions; in the present case, that was alternative C, the tightest of the three. Another alternative always shown involved the longer-run growth rate for M1 adopted by the Committee at its previous meeting. Since on this occasion that alternative called for a rather sizeable near-term decline in the Federal funds rate followed by an upturn before the end of the 6-month projection period, the staff thought it probably would be as liberal a policy as the committee was likely to consider within the range of reasonableness. Consequently, that alternative was labeled "A," and the third was formulated to fall between the other two." (MOD, 1/21/75, pp. 61-2).

quarter, as in the February 4 Bluebook, or also included the next quarter ahead, as in the March 4 Bluebook, horizons of the Bluebook conditional money supply forecasts were eventually lengthened to four-quarter horizons in 1975, including the current quarter, $h = 0, 1, 2, 3$.

Empirical evidence for intermediate targeting in the Burns/Miller era

Intermediate targeting of the money supply is summarized by three equations,

$$\Delta m_t = \pi_t + \Delta y_t - \Delta v_t, \tag{33}$$

$$\Delta \bar{m}_t = \bar{\pi}_t + \Delta \bar{y}_t - \Delta \bar{v}_t, \tag{34}$$

$$r^*_{t_f} = \bar{\rho}_t + \bar{\pi}_t + c_{2,t}(\Delta m_t - \Delta \bar{m}_t + (\Delta v_t - \Delta \bar{v}_t)), \tag{35}$$

where equation (33) is the monetarist equation of exchange that links Greenbook forecasts of inflation and output growth to the projected growth of the monetary aggregate. Equation (34) is a natural rate variant that indicates what target growth of the monetary aggregate is consistent with the natural rates for inflation and output growth. The desired setting of the funds rate at the FOMC meeting in period t_f is defined by equation (35). This is an adjusted variant of intermediate targeting, where monetary aggregate growth is adjusted for the staff prediction of transient velocity growth.[59]

Substituting the first two equations, (33) and (34), into the third equation (35), gives the desired funds rate explicitly conditioned on averages of Greenbook forecasts,

$$\begin{aligned} r^*_{t_f} &= \bar{\rho}_t + \bar{\pi}_t + c_{2,t}((\pi^k_t - \bar{\pi}_t) + (\Delta y^k_t - \Delta \bar{y}_t)), \\ &= \bar{\rho}_t + \bar{\pi}_t + c_{2,t}(x^k_t - \bar{x}_t), \end{aligned} \tag{36}$$

where $x^k_t - \bar{x}_t$ is a proxy for the gap of nominal output growth using Okun's Law, $x^k_t - \bar{x}_t = \pi^k_t - \bar{\pi}_t - a' \Delta u^k_t$;[60] and the superscript, k, indicates averaging over forecast periods through $h = k$.

[59] By construction, a persistent shift in trend velocity alters the natural rate estimate, $\Delta \bar{v}_t$. "Shift-adjusted" monetary aggregate targets, to account for the estimated effects of financial innovations such as the nationwide introduction of negotiable order of withdrawal (NOW) accounts, were not publically announced until 1981. The transient velocity growth adjustment, $\Delta v_t - \Delta \bar{v}_t$, of equation (35) approximates the "zone of indifference" the FOMC adopted in the 1970s to accommodate transient movements within growth rate target ranges. The evolution of the "zone of indifference" is illustrated by the following selections from the *Memorandum of Discussion*: "On balance he would not object to some shading of the funds rate if the aggregate growth rates appeared to be close to the upper or lower limits. However, more vigorous action should be taken only if the growth rates appeared to be outside the range." Burns, (MOD 10/17/72, p.40). "Chairman Burns remarked at the last meeting he had initially defined the ranges for the aggregates as zones of no action. He had then modified that–in response to Mr. Holmes' remarks–to provide for a movement in the funds rate of up to but no more than 1/8 of 1 percentage point as the aggregates approached their limits. In the event that the aggregates appeared to be moving beyond their limits, however, full and free use was to be made of the range for the funds rate." (MOD, 11/20/72 p. 50). "(Governor Partee's) preference was for (a range) of 4 to 8...for M-1...with a zone of indifference of 5 to 7....Chairman Burns observed that he could accept the zones of indifference proposed by Mr. Partee." (MOD, 3/16/76, p.74).

[60] As discussed earlier, the Okun's Law coefficient, $a' = 2.2$, is based on estimates for the 1970s in Tatom (1977).

Note that equation (36) is a restricted version of the desired funds rate equation specified earlier in (30). Three restrictions are required by money growth intermediate targeting: First, the policy response to the unemployment gap is zero, $c_{3,t} = 0$. Second, the difference in the unemployment rate, Δu_t^k, is averaged over the same number of periods as the inflation rate regressor. Third, the long-run policy responses to the inflation average, π_t^k, and the average of the unemployment rate difference proxy, $-a'\Delta u_t^k$, are the same, $c_{2,t}$. The dynamic adjustment of the funds rate is the same as that specified earlier in equation (31).

Time-varying estimates of the policy rate response equation implied by money growth intermediate targeting are presented in Table 11, for two-quarter averages of Greenbook forecasts, $h = 0, 1$, and in Table 12, for four-quarter forecast averages, $h = -2, -1, 0, 1$.

In both Tables 11 and 12, equations in the bottom panels are estimates of the policy response equation when all three restrictions associated with intermediate targeting of the money growth are imposed. The unemployment gap regressor, $u_{t+k} - \bar{u}_t$, is added to equations in the top panels of Tables 11 and 12. Similar to the results in section 4, the estimated mean policy responses to the unemployment gap, $\bar{\beta}_3$, are statistically insignificant. In addition, the average difference in the unemployment rate, Δu_t^k, is added to the equations reported in the middle panels of Tables 11 and 12. These equations also indicate that the mean policy response of the Burns/Miller sample to the difference in the unemployment rate does not differ significantly from the response expected under money growth intermediate targeting.

The p-values of the mean policy response to the nominal growth proxy, x_t, are smaller for the four-quarter averages (reported in the bottom panel of table 12) than for the two-quarter averages (reported in the bottom panel of Table 11).[61] Although not shown, the estimated long-run policy responses, $c_{2,t}$, to the nominal growth proxies, x_t, implied by the tvp estimators in the bottom panel of Table 12 move between 0.5 and 0.7 during the 1970s. Thus, the implied long-run responses to inflation are even further below one than those estimated in section 4 for the Burns/Miller sample.

Finally, differences between the natural rate for inflation implied by Greenbook forecasts, $\bar{\pi}_t$, and estimates of private agent perceptions of the central bank target for inflation, $\bar{\pi}_t^p$, are charted in Figure 10. The two thick lines are estimates of $\bar{\pi}_t$ for the Burns/Miller era from 1970Q1 through 1979Q2 (from the SC estimator in the bottom panel of Table 12), and for the Volcker/Greenspan sample from 1979Q3 through 1997Q4 (from the SC estimator in the middle panel of Table 10). The thick dashed line is a concatenation

[61] A likelihood ratio comparison also slightly favors the four-quarter variant of the SC specifications.

of survey estimates of long-term inflation expectations by private agents. [62] The thin line is an estimate of private sector perceptions of the central bank target for inflation from Kozicki and Tinsley (2001a). [63]

Using the vertical distance between the private perception, $\bar{\pi}_t^p$, and the central bank target for inflation, $\bar{\pi}_t$, as a measure of the credibility of the US central bank, Figure 10 suggests that credibility was positive and large at the beginning of the 1970s and steadily evaporated over the decade. By the beginning of the 1980s, the gap in credibility was negative and quite large, about five percentage points, and only slowly returned to a value near zero by the end of the sample.

Consequences of money growth intermediate targeting

The most striking outcomes of the tvp estimators of policy in the 1970s are the rather high estimates of the central bank target for inflation, $\bar{\pi}_t$, and the uniformly low estimates of the long-run policy responses, $c_{2,t}$.

A monetary policy that targets the growth rate of the money supply is vulnerable to two types of fundamental shocks, and both occurred in the 1970s. Renormalizing equation (34), the effective central bank target for inflation under intermediate targeting is defined by

$$\bar{\pi}_t = \Delta\bar{m}_t - \Delta\bar{y}_t + \Delta\bar{v}_t. \tag{37}$$

Given a target growth rate for the money supply, $\Delta\bar{m}_t$, the effective inflation target is increased if the central bank is unable to detect a reduction in the natural rate trend of output, $\Delta\bar{y}_t$, or an increase in trend velocity, $\Delta\bar{v}_t$. The natural rate of trend output growth slowed in the late 1960s and early 1970s.[64] Subsequently, due to financial innovations fuelled by higher inflation and deregulation of banking and financial markets, the trend of velocity began a long march of upward shifts in the mid-1970s. Both the reduction in $\Delta\bar{y}$ and the increase in $\Delta\bar{v}$ induced increases in the effective natural rate of inflation in the 1970s.

Note that the policy errors caused by erroneous predictions of trend velocity are unique to a policy based on money supply intermediate targeting. The unpredicted shifts in trend velocity were not small. The December 12, 1980 Bluebook contains an analysis of money demand models. Conditioned on retrospective measurements of explanatory variables, the annual underestimate of velocity growth over the last half of

[62] Until July 1990, survey estimates are drawn from the Hoey survey of expected inflation in the second five years of a 10-year forecast horizon. The remainder of the series is long-run expected inflation from the Survey of Professional Forecasters, published by the Federal Reserve Bank of Philadelphia.

[63] This estimate is based on multinomial logit aggregation of alternative shift estimators of $\bar{\pi}_t$. Although the perceived natural rate estimate is similar to the survey of long-term expected inflation, survey information was not used in the estimated learning model of private sector perceptions.

[64] See a literature review of estimated shifts in trend productivity in Bullard and Duffy (2004).

the 1970s by the 1980 vintage of the staff model was 1.8%, including errors of 5.1% in 1975 and 2.9% in 1976.[65]

The second unusual characteristic of policy in the 1970s is that the estimated long-run policy response to the money supply growth proxy, $c_{2,t}$, remained well below one in the Burns/Miller sample.

Contemporaneous critiques of money growth targeting in the 1970s included criticism of the relatively tight FOMC ranges on inter-meeting variations of the policy rate, vid. Poole (1975). The inter-meeting tolerance ranges on the policy rate are charted in Figure 11. It is evident that tight inter-meeting ranges did not prevent sizeable meeting-to-meeting adjustments of the policy rate in 1973 and 1974. By contrast, FOMC decisions led to only modest meeting-to-meeting adjustments of the policy rate level after 1974, until the large upward adjustments of the policy rate in the initial FOMC meetings chaired by Paul Volcker.

The passivity of policy through much of the second-half of the 1970s is also illustrated in Figure 12 where the policy rate is plotted against the Greenbook prediction of the four-quarter average of the nominal growth proxy, $x^1_t = \frac{1}{4}\sum_{h=-2}^{1} x_{t+h}$. Even if velocity had been perfectly predicted, variations of the funds rate did not keep pace with Greenbook predicted movements of nominal growth.

One interpretation of the 1970s is that the FOMC did not believe it had popular support for large increases in the policy rate, vid. DeLong (1997) and Meltzer (2004). This explanation is not consistent with policy actions in mid-1974, when the funds rate was driven near 13%, nor with discussion in the FOMC *Memorandum of Discussion*:

> "Chairman Burns said he might offer his appraisal of the existing support for current Federal Reserve policy. He agreed that support in Congress was strong; he had been receiving almost no critical mail from that source. Of the letters that reached his desk from individuals across the country, a majority were still commendatory." (MOD, 6/18/74, p.62).

> "More generally, in his many recent conversations with Congressman he had found widespread acceptance of the need for slow economic growth: they reported their constituents were more anxious about inflation than unemployment." Burns (MOD, 7/16/74, p.34) [66]

[65]Goldfeld (1976) indicates that a representative money demand model of the early 1970s generates larger prediction errors, with an out-of-sample RMSE of 6.3% from 1974Q1 to 1975Q2.

[66]It might be noted that these real-time quotes differ considerably from the retrospective Per Jacobsson Lecture where Burns (1979) suggests: "As the Federal Reserve, for example, kept testing and probing the limits of its freedom to undernourish the inflation, it repeatedly evoked violent criticism from both the Executive Branch and the Congress."

Another possible interpretation is that the FOMC may have become disenchanted with intermediate targeting of the monetary aggregates in the mid-1970s. The role of intermediate targets in operational policy was reviewed in the Stage II report of the Subcommittee on the Directive (1976) distributed to FOMC members in early 1976.[67] The initial portion of this report reviewed a staff proposal that the policy instrument, such as the funds rate or nonborrowed reserves, directly target ultimate objectives, such as unemployment and inflation, relegating the money supply to one of many potential indicators of unobserved movements in ultimate objectives. However, the remainder of the report endorsed the two-stage strategy of intermediate targeting with monetary aggregates. FOMC discussion of this report in the 3/15/76 meeting supported a continuation of intermediate targeting:

> ”Mr. Wallich added that if optimal control were applied to monetary policy it would tend to focus attention on such ultimate objectives as full employment and price stability. However, he had strongly endorsed the Subcommittee's recommendation that monetary policy continue to focus primarily on intermediate objectives, rather than on ultimate objectives....In further discussion individual members of the Subcommittee commented on the reasons why they had not favored directly relating an operational instrument, such as nonborrowed reserves or the federal funds rate, to ultimate objectives. These reasons included the difficulty of linking instrumental variables to ultimate objectives, both intuitively or through use of econometric models; the problem of reaching an agreement on necessary tradeoffs among ultimate objectives; and the complications created by the fact that monetary policy was but one of many influences on the ultimate objectives.” (MOD, 3/15/76, p.16)

The FOMC *Memorandum of Discussion* (MOD) suggests several issues that may have contributed to passive responses to nominal growth gaps.

One possibility is that the FOMC may been optimistic about interest rate elasticities, selecting policy rate adjustments that were too small to reverse predicted nominal growth gaps.[68] In particular, two procedures could have led to effective overstatement of interest rate effects:

In framing final voting choices, FOMC members were free to pick policy rates from one Bluebook option and monetary target ranges from another option. The problem of inconsistent choices from an “a la

[67]The Subcommittee was chaired by Governor Holland, with Governor Wallich, President Balles (Federal Reserve Bank of San Francisco), and President Morris (Federal Reserve Bank of Boston) as members.

[68]The full system interest rate elasticity of the money supply is necessarily greater than the interest rate elasticity of nominal output if the interest rate elasticity of money demand is also negative.

carte menu" was occasionally addressed in Bluebook presentations.

"The blue book can be viewed as a menu of consistent targets....The Committee is, of course, free to choose among the various objectives presented, taking due account of the risks being run. There is the risk, for instance, of choosing incompatible objectives. However, this risk has to be weighed against the probability there will be errors in the staff's estimates of relationships likely to prevail among bank reserves, monetary aggregates, and interest rates." Axilrod, FOMC Economist (MOD, 11/20/72, p.43)

A more direct route to optimistic views of interest rate effects is that projections of interest rates associated with alternative options were judgmentally adjusted by senior staff. Especially after staff models began to overpredict M_1 growth in the mid-1970s, there appear to have been nontrivial downward judgmental adjustments of interest rate changes associated with alternative money growth paths.

"(Mr. Partee) believed that (interest) rates would be especially high if the rate of growth in M1 was at the midpoint of the Committee's long-run range....Actually, the econometric model had yielded still higher rates, but the staff believed the model tended to overstate rate increases." (MOD, 8/19/75, p.58)

"Mr. Gramley said there was considerable uncertainty about the projections of interest rates, which were among the most difficult variables to project. As Committee members knew, the staff tended to make rather large judgmental adjustments to the interest rate projections produced by the model. In the latest projection,...the model had produced a short-term interest rate in the fourth quarter of 1976 that was 2-3/4 percentage points above the staff's judgementally projected rate." (MOD, 9/16/75, p.25)

"In view of recent projection errors of the model, the staff had tended to lower the level of interest rates it associated with any assumed rate of monetary growth." Axilrod (MOD, 11/18/75, p.33)

A second interpretation of the effective passivity of policy is that increased uncertainty about properties of empirical money demand functions after the mid-1970s may have induced more cautious policy adjustments.

"Shortfalls in M1 growth may also reflect a weakening of economic activity relative to staff projections....one option for the Committee to consider is whether it wishes to await somewhat more sustained weakness in M1 before contemplating a policy that permits relatively sizeable interest rate declines." Axilrod, FOMC Associate Economist (MOD, 9/10/74, pp.35)

“In recent years, the Committee had been focusing more on monetary aggregate targets because of the problems it had experienced earlier with interest rate targets. At present there would be less risk associated with a reduction in interest rates than, say, 2 months ago, both because the aggregates had been falling short of the Committee’s targets and because the economic outlook had weakened considerably. Even so, the precise consequences of a sharp reduction in interest rates remained unclear. Growth in the aggregates would be stepped up substantially, but it is hard to say by how much; and the effects, over time, that the rate reduction would have on expectations and on spending behavior were highly uncertain. To advocate a prompt, sizeable reduction in rates was to ignore all such uncertainties.” Partee, FOMC Senior Economist (MOD, 12/17/74, p.71)

”The actual stock of money has been running well short of what either our quarterly or monthly money market models would have predicted for some time, given actual GNP and interest rates....given uncertainties with respect to the meaning of recent money supply behavior as well as still unresolved issues affecting the municipal market, the committee may wish to consider giving somewhat more weight than usual to money market conditions in framing its instructions.” Axilrod, FOMC Economist (MOD, 11/18/75, pp.33-5)

”Mr. Volcker said he felt rather strongly that the right approach to policy today was to hold interest rates fairly steady....Mr. Axilrod’s remarks, which he had found stimulating and even persuasive, provided a further indication of how little was known about the short-term relationship between interest rates and the money supply....because he was concerned about the uncertainties in the business outlook and the possible implications of the New York City situation, he would not want to raise interest rates even if the monetary aggregates should strengthen in the period immediately ahead.” (MOD, 11/18/75, p. 39)

”Mr. Axilrod said he felt highly uncertain about the current projection. In particular, he was not sure whether the demand for money would keep shifting down, stabilize, or shift back up.” (MOD, 3/16/76, p. 60)

”(A)n additional element of uncertainty was introduced by the disparity between the projections made by the New York staff and those made by the Board staff for the coming period–with the former showing stronger growth, particularly for M1. Against that background, this did not seem to him to be an appropriate time for a major change in policy.....Turning to the specifications for the Federal funds rate, he favored maintaining the present range and keeping the rate at about its current 4-3/4 per cent level." Volcker (MOD, 3/16/76, pp. 63-4)

Finally, a third conjecture concerning the framing of policy choices is that differences in the underlying relationships and forecast horizons of the short-run policy options of the Bluebook and of the multiperiod predictions of the Greenbook may have made it difficult for FOMC deliberations to connect current policy decisions to longer-run predicted outcomes.[69]

"Mr. MacLaury remarked that he was disturbed by what he perceived as a lack of clarity in the Committee's methodology. While the Committee now was publicly announcing its longer-term targets, he has less confidence than before in his understanding of the path by which these objectives were to be achieved....it seemed strange for the blue book to state that all of the three alternatives it presented were generally consistent with the 12-month ranges. He believed it made a difference whether the Committee embarked on the path indicated by the high alternative or on that indicated by the low alternative." (MOD, 5/20/75, p.59)

6 Concluding remarks

Forward-looking macro models provide valuable insights for central bank policy discussions, by integrating the forward expectations of households and firms with the forward expectations of traders in financial markets. In well-behaved models, these forward expectations are anchored by the natural rates for unemployment, $\bar{u}$, and inflation, $\bar{\pi}$, where the latter is the central bank target for inflation.

As discussed in section 1, recent work demonstrates that properties of empirical forward-looking macro models are improved if the natural rates are time-varying, and allowance is made for differences in natural rate perceptions among private and public agents. This paper provides estimates of the US central bank perceptions of natural rates for unemployment and inflation, using the Greenbook forecasts presented at FOMC meetings from the mid-1960s through the mid-1990s.

[69]Judgemental adjustments of interest rates associated with alternative policy options, discussed earlier, were motivated not only by money demand forecast errors in the 1970s but also by differences among competing staff models, such as the monthly money market model used in Bluebook analyses and quarterly models used for Greenbook analyses. "Mr. Gramley replied that the staff's interest rate projections depended on the relationship between growth in money and growth in nominal GNP. Personal income was used only in the monthly model, because no better monthly indicators of aggregate expenditures was available....Mr. Axilrod remarked that recent work done by the Board's staff indicated that in the first year of recovery interest rate projections based on nominal GNP were too high while those based on personal income were too low. In making its interest rate projections for the blue book, the staff had taken those results into account." (MOD, 9/16/75, pp. 32-3) As noted earlier, it is not historically accurate to assume that all judgemental forecast adjustments were confined to intercept adjustments. Kalchbrenner and Tinsley (1977) discuss differences between policy use of auxiliary measurements and use of competing models.

The theoretical basis for time-varying natural rates is developed in section 2, along with descriptions of the state space modelling framework that is used to organize the multiperiod Greenbook forecasts and to estimate time-varying natural rates, using both atheoretic time series and structural macro models with time-varying parameters.

Several recent studies have suggested that the US central bank substantially underestimated the natural rate for economic activity, either output or the unemployment rate, in the 1970s. Empirical results in section 3 support some underestimation of the natural rate of unemployment, but the natural rate errors were relatively modest and unlikely to be a major factor in staff underpredictions of inflation in the 1970s.

Natural rate estimates of inflation implied by inflation autoregressions and policy rate responses to Greenbook forecasts are presented in sections 4 and 5. Under asymmetric information, atheoretic autoregressions capture weighted averages of the central bank target for inflation and private perceptions of the inflation target. Unlike preceding analyses of US monetary policy, the results of the estimated policy rate responses suggest the central bank target for inflation not only varied over time but was substantially different from private sector perceptions in the 1970s and 1980s.

Of the two leading empirical interpretations of the Great Inflation, the *passive policy* description is perhaps the most optimistic, as empirical analyses of historical US monetary policy generally indicate stable policy responses have been maintained since the 1980s. The *natural rate error* description has a seductive appeal for central banks for it suggests that unlucky mistakes were made, but carries also the pessimistic inference that these mistakes will likely occur in the future. The empirical evidence presented in section 5 indicates that monetary policy in the 1970s is better represented by money growth intermediate targeting. This implies that US central bank errors in estimating natural rate gaps for output or the unemployment rate are largely irrelevant to explanations of the Great Inflation.

The empirical evidence in section 5 also supports the passive policy interpretation, as adjustments of the central bank policy rate in the 1970s were not sufficiently vigorous to result in stable responses to movements in inflation. However, the passive policy interpretation is merely a description of unstable policy, not an explanation. A description of the Great Inflation based on intermediate targeting of money supply growth offers a neglected search area for explanations of passive policy responses.

Given the advantage of hindsight, there will always be mistakes in the execution of monetary policy, including errors in estimating current values of natural rates. The deeper flaw of intermediate targeting in the 1970s is that it shifted the official gauge of policy performance from inflation and economic activity to the growth rate of the money supply. Empirical results in this paper support the assessment of the architect of the monetarist strategy that dominated US monetary policy during the Great Inflation: "The use of the quantity of money as a target has not been a success," Friedman (2003).

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Table 1: Unemployment natural rates (%),
with tvp autoregressions

	natural rate source			
policy regime	CBO (2004)	Romer & Romer (2002)	$AR(4)$ [1] $h=0,\ldots,H$	$AR(4)$ [1] $h=3,\ldots,H$
Martin 67Q4-69Q4	5.8	2.5	5.3	n.a.
Burns_1 70Q1-75Q2	6.0	3.1	6.2	6.6
Burns_2 75Q3-78Q1	6.2	8.2	6.6	6.5
Miller 78Q2-79Q2	6.3	4.6	7.1	6.9
Volcker 79Q3-87Q2	6.1	8.0	7.4	6.6
Greenspan_1 87Q3-96Q4	5.7	6.7	6.2	6.1
Greenspan_2 96Q1-97Q4	5.2	n.a.	5.5	6.0

1. Based on the stationary coefficient variants of the fourth-order autoregressions in Table 2.

Table 2: Unemployment autoregressions[1]

$$u_{t+h} = \beta_{1,t} + \beta_{2,t} u_{t+h-1} + \beta_{3,t} \Delta u_{t+h-1} + \beta_{4,t} \Delta u_{t+h-2} + \beta_{5,t} \Delta u_{t+h-3} + a_{t+h}.$$
$$\bar{u}_t = \beta_{1,t}/(1-\beta_{2,t}).$$

tvp format	estimated $\bar{\beta}_i$ [2]					estimated $\bar{u}_t$	
	GB horizon forecasts, $h = 0, \ldots, H$ [3]						
	$\bar{\beta}_1$	$\bar{\beta}_2$	$\bar{\beta}_3$	$\bar{\beta}_4$	$\bar{\beta}_5$	max	min
random walk intercept	.487 (.052)	.926 (.004)	.478 (.017)	.022 (.017)	.050 (.014)	8.5	5.0
random walk coefficients	.499 (.221)	.924 (.035)	.386 (.368)	.034 (.268)	.078 (.190)	8.7	4.9
stationary coefficients	.476 (.052)	.924 (.007)	.314 (.052)	.082 (.043)	.093 (.021)	8.5	4.9
(var decomp %)	61	38	1	0	0		
	GB horizon forecasts, $h = 3, \ldots, H$ [4]						
	$\bar{\beta}_1$	$\bar{\beta}_2$	$\bar{\beta}_3$	$\bar{\beta}_4$	$\bar{\beta}_5$	max	min
random walk intercept	.217 (.018)	.966 (.003)	.511 (.027)	.145 (.026)	-.011 (.014)	7.4	5.8
random walk coefficients	.247 (.100)	.961 (.016)	.466 (.237)	.133 (.188)	.002 (.142)	7.4	5.8
stationary coefficients	.223 (.035)	.965 (.006)	.455 (.088)	.141 (.064)	.006 (.027)	7.1	6.0
(var decomp %)	26	73	1	0	0		

1. $u_{t+h}-$ GB forecast civilian unemployment, $h \geq 0$.

2. (.) - std error; $\bar{\beta}_i-$ sample average of $\beta_{i,t}$ for random walk specifications.

3. sample 1966Q3-1997Q4.

4. sample 1969Q1-1997Q4.

Table 3: Pricing equation
w/ autoregressive expected inflation [1]

$$\pi_{t+h} = \beta_{1,t} + \beta_{2,t}u_{t+h} + E_t\pi_{t+h+1} + a_{t+h}.$$
$$E_t\pi_{t+h+1} = \pi_{t+h-1} + \beta_{3,t}\Delta\pi_{t+h-1}.$$
$$\bar{u}_t = -\beta_{1,t}/\beta_{2,t}.$$

tvp format	estimated $\bar{\beta}_i$ [2]			estimated $\bar{u}_t$	
	random walk expected inflation				
	$\bar{\beta}_1$	$\bar{\beta}_2$	$\bar{\beta}_3$	max	min
random walk intercept	.421 (.095)	-.083 (.016)		6.9	3.3
random walk coefficients	.396 (.459)	-.078 (.068)		7.1	3.1
stationary coefficients (var decomp %)	.408 (.142) 20	-.085 (.029) 80		7.0	3.9
	AR(2) expected inflation				
	$\bar{\beta}_1$	$\bar{\beta}_2$	$\bar{\beta}_3$	max	min
random walk intercept	.478 (.092)	-.097 (.016)	-.213 (.022)	6.9	3.0
random walk coefficients	.431 (.434)	-.087 (.065)	-.212 (.175)	7.3	2.6
stationary coefficients (var decomp %)	.506 (.130) 7	-.109 (.026) 93	-.260 (.035) 0	7.0	3.8

1. sample 1969Q1-1997Q4; $\pi_{t+h}-$ GB forecast GNP/GDP deflator inflation; $u_{t+h}-$ GB forecast civilian unemployment, $h = 3, \ldots, H$.
2. (.) - std error; $\bar{\beta}_i-$ sample average of $\beta_{i,t}$ for random walk specifications.

Table 4: Pricing equation
w/ Greenbook expected inflation [1]

$$\pi_{t+h} = \beta_{1,t} + \beta_{2,t}u_{t+h} + \beta_{3,t}\Delta\pi_{t+h-1} + \beta_{4,t}\Delta u_{t+h+1} + \beta_{5,t}(\pi_{t+h+1} - \pi_{t+h-1}) + \pi_{t+h-1} + a_{t+h}.$$

$$\bar{u}_t = -\beta_{1,t}/\beta_{2,t}.$$

tvp format	estimated $\bar{\beta}_i$ [2]					estimated $\bar{u}_t$	
	Greenbook expected inflation						
	$\bar{\beta}_1$	$\bar{\beta}_2$	$\bar{\beta}_3$	$\bar{\beta}_4$	$\bar{\beta}_5$	max	min
random walk intercept	.117 (.068)	-.019 (.013)		-.077 (.103)	.573 (.021)	9.3	4.0
random walk coefficients	.082 (.383)	-.015 (.058)		-.032 (.644)	.582 (.153)	947	-88.3
stationary coefficients (var decomp %)	.171 (.099) 46	-.029 (.016) 54		-.087 (.188) 0	.567 (.052) 0	7.1	5.5
	tvp averaging of Greenbook and autoregressive expected inflation						
	$\bar{\beta}_1$	$\bar{\beta}_2$	$\bar{\beta}_3$	$\bar{\beta}_4$	$\bar{\beta}_5$	max	min
random walk intercept	.173 (.067)	-.030 (.014)	-.072 (.018)	-.138 (.103)	.543 (.022)	6.9	4.5
random walk coefficients	.107 (.371)	-.022 (.057)	-.072 (.134)	-.083 (.649)	.558 (.137)	1746	-11.9
stationary coefficients (var decomp %)	.209 (.099) 42	-.038 (.016) 58	-.075 (.030) 0	-.156 (.203) 0	.538 (.046) 0	6.7	4.8

1. sample 1969Q1-1997Q4; $\pi_{t+h}-$ GB forecast GNP/GDP deflator inflation, $u_{t+h}-$ GB forecast civilian unemployment, $h = 3, \ldots, H$.
2. (.) - std error; $\bar{\beta}_i-$ sample average of $\beta_{i,t}$ for random walk specifications.

Table 5: Unemployment natural rates (%), given alternative expected inflation specifications

	natural rate source				
policy regime	Romer & Romer (2002)	random walk[1] expectations	AR(2)[1] expectations	Greenbook[2] expectations	tvp averaging[2] expectations
Burns_1 70Q1-75Q2	3.1	4.2	3.9	5.8	5.2
Burns_2 75Q3-78Q1	8.2	4.4	4.3	5.6	5.3
Miller 78Q2-79Q2	4.6	4.6	4.3	5.6	5.3
Volcker 79Q3-87Q2	8.0	5.7	5.4	5.7	5.6
Greenspan_1 87Q3-96Q4	6.7	5.6	5.7	6.5	6.2
Greenspan_2 96Q1-97Q4		5.1	5.0	5.8	5.6

1. Based on stationary coefficients equations presented in Table 3.
2. Based on stationary coefficients equations presented in Table 4.

Table 6: Inflation autoregressions [1]

$$\pi_{t+h} = \beta_{1,t} + \beta_{2,t}\pi_{t+h-1} + \beta_{3,t}\Delta\pi_{t+h-1} + \beta_{4,t}\Delta\pi_{t+h-2} + \beta_{5,t}\Delta\pi_{t+h-3} + a_{t+h}.$$
$$\bar{\pi}_t = \beta_{1,t}/(1-\beta_{2,t}).$$

tvp format	estimated $\bar{\beta}_i$ [2]					estimated $\bar{u}_t$	
	$\bar{\beta}_1$	$\bar{\beta}_2$	$\bar{\beta}_3$	$\bar{\beta}_4$	$\bar{\beta}_5$	max	min
random walk	.371	.887	-.229	-.131	-.080	4.8	1.7
intercept	(.079)	(.011)	(.028)	(.021)	(.014)		
random walk	.408	.887	-.280	-.154	-.101	5.2	1.1
coefficients	(.150)	(.041)	(.165)	(.120)	(.077)		
stationary	.368	.875	-.390	-.214	-.128	5.2	1.0
coefficients	(.060)	(.020)	(.098)	(.031)	(.021)		
(var decomp %)	39	64	-4	1	0		

1. $\pi_{t+h}-$ GB forecast GNP/GDP deflator inflation, $h = 3, \ldots, H$; sample 1969Q1-1997Q4.

2. (.) - std error; $\bar{\beta}_i-$ sample average of $\beta_{i,t}$ for random walk specifications.

Table 7: Federal Funds Rate Policy Rule,
full sample[1]

$$r_t^* = \bar{\rho}_t + \bar{\pi}_t + c_{2,t}(\pi_t^k - \bar{\pi}_t) + c_{3,t}(u_{t+1} - \bar{u}_t) + c_{4,t}\Delta u_t,$$

$$r_t = (1-\beta_{6,t})r_t^* + \beta_{5,t}\Delta r_{t-1} + \beta_{6,t}r_{t-1} + a_t,$$
$$= \beta_{1,t} + \beta_{2,t}\pi_t^k + \beta_{3,t}(u_{t+1} - \bar{u}_t) + \beta_{4,t}\Delta u_t + \beta_{5,t}\Delta r_{t-1} + \beta_{6,t}(r_{t-1} - \bar{\rho}_t) + \bar{\rho}_t + a_t,$$

$$\bar{\pi}_t = -\beta_{1,t}/(\beta_{2,t} + \beta_{6,t} - 1).$$

tvp format	estimated $\bar{\beta}_i$ [2]						estimated $\bar{\pi}_t$	
	$\bar{u}_t$, preferred estimate[3]							
	$\bar{\beta}_1$	$\bar{\beta}_2$	$\bar{\beta}_3$	$\bar{\beta}_4$	$\bar{\beta}_5$	$\bar{\beta}_6$	max	min
random walk intercept	.060	.101	-.058	-.166	.439	.896	49.4	-13.0
	[.69]	[.00]	[.01]	[.03]	[.03]	[.00]		
random walk coefficients	-.018	.140	-.056	-.263	.403	.873	76.6	-240.6
	[.97]	[.45]	[.58]	[.67]	[.49]	[.00]		
stationary coefficients	-.082	.160	-.065	-.252	.402	.871	229.1	-14.6
	[.28]	[.00]	[.00]	[.00]	[.01]	[.00]		
(var decomp %)	11	34	1	0	0	54		
	$\bar{u}_t^b$, lower bound estimate[4]							
	$\bar{\beta}_1$	$\bar{\beta}_2$	$\bar{\beta}_3$	$\bar{\beta}_4$	$\bar{\beta}_5$	$\bar{\beta}_6$	max	min
random walk intercept	.062	.098	-.043	-.164	.445	.902	488.5	-76.6
	[.69]	[.00]	[.04]	[.03]	[.00]	[.00]		
random walk coefficients	-.003	.134	-.038	-.238	.402	.879	257.4	-228.8
	[.99]	[.47]	[.65]	[.70]	[.48]	[.00]		
stationary coefficients	-.061	.145	-.032	-.234	.401	.882	10.6	-113.8
	[.41]	[.00]	[.09]	[.01]	[.00]	[.00]		
(var decomp %)	10	34	1	0	0	55		

1. sample 1969Q1-1997Q4; $r-$ avg federal funds rate in FOMC meeting-to-meeting intervals; u - GB unemployment rate forecast; π^k - GB annualized inflation, averaged over the forecast periods, h = 0,1.
2. $[\,.\,]$ - p-values; $\bar{\beta}_i-$ sample average of $\beta_{i,t}$ for random walk specifications.
3. Implied by stationary coefficients equation, lower panel of Table 4.
4. Implied by stationary coefficients equation, lower panel of Table 3.

Table 8: Federal Funds Rate Policy Rule,
Burns/Miller sample (h = 0,1)[1]

$$r_t^* = \bar{\rho}_t + \bar{\pi}_t + c_{2,t}(\pi_t^k - \bar{\pi}_t) + c_{3,t}(u_{t+1} - \bar{u}_t) + c_{4,t}\Delta u_t,$$

$$\begin{aligned} r_t &= (1-\beta_{6,t})r_t^* + \beta_{5,t}\Delta r_{t-1} + \beta_{6,t}r_{t-1} + a_t, \\ &= \beta_{1,t} + \beta_{2,t}\pi_t^k + \beta_{3,t}(u_{t+1} - \bar{u}_t) + \beta_{4,t}\Delta u_t + \beta_{5,t}\Delta r_{t-1} + \beta_{6,t}(r_{t-1} - \bar{\rho}_t) + \bar{\rho}_t + a_t, \end{aligned}$$

$$\bar{\pi}_t = -\beta_{1,t}/(\beta_{2,t} + \beta_{6,t} - 1).$$

tvp format	estimated $\bar{\beta}_i$ [2]						estimated $\bar{\pi}_t$	
	$\bar{\beta}_1$	$\bar{\beta}_2$	$\bar{\beta}_3$	$\bar{\beta}_4$	$\bar{\beta}_5$	$\bar{\beta}_6$	max	min
random walk	.105	.066	-.033	-.112	.546	.925	12.5	8.2
intercept	[.04]	[.15]	[.38]	[.25]	[.00]	[.00]		
random walk	.126	.077	-.043	-.108	.537	.915	77.1	-73.4
coefficients	[.48]	[.15]	[.34]	[.41]	[.00]	[.00]		
stationary	.083	.073	-.033	-.124	.537	.922	133.9	-169.9
coefficients	[.57]	[.12]	[.40]	[.23]	[.00]	[.00]		
(var decomp %)	20	41	1	0	0	38		
random walk	.133	.066	-.040		.589	.919	10.3	6.3
intercept	[.01]	[.15]	[.29]		[.00]	[.00]		
random walk	.140	.076	-.043		.569	.911	55.0	-38.0
coefficients	[.45]	[.16]	[.36]		[.00]	[.00]		
stationary	.092	.078	-.035		.585	.915	348.5	-167.5
coefficients	[.53]	[.10]	[.36]		[.00]	[.00]		
(var decomp %)	23	39	1		0	37		
random walk	.112	.047		-.125	.552	.936	7.4	5.6
intercept	[.03]	[.25]		[.20]	[.00]	[.00]		
random walk	.129	.051		-.115	.550	.931	11.5	6.4
coefficients	[.47]	[.26]		[.38]	[.00]	[.00]		
stationary	.099	.052		-.131	.546	.933	8.3	6.5
coefficients	[.48]	[.19]		[.20]	[.00]	[.00]		
(var decomp %)	20	39		0	0	40		

1. sample 1970Q1-1979Q2; $r-$ avg federal funds rate in FOMC meeting-to-meeting intervals; $\bar{u}_t$ - tvp avg expectations; π^i - GB annualized inflation forecasts, averaged over the forecast periods, h = 0,1.
2. $[\,.\,]$ - p-values; $\bar{\beta}_i-$ sample average of $\beta_{i,t}$ for random walk specifications.

Table 9: Federal Funds Rate Policy Rule
Burns/Miller sample (h = -2, -1, 0,1) [1]

$$\begin{aligned} r_t^* &= \bar{\rho}_t + \bar{\pi}_t + c_{2,t}(\pi_t^k - \bar{\pi}_t) + c_{3,t}(u_{t+1} - \bar{u}_t) + c_{4,t}\Delta u_t, \\ r_t &= (1-\beta_{6,t})r_t^* + \beta_{5,t}\Delta r_{t-1} + \beta_{6,t}r_{t-1} + a_t, \\ &= \beta_{1,t} + \beta_{2,t}\pi_t^k + \beta_{3,t}(u_{t+1} - \bar{u}_t) + \beta_{4,t}\Delta u_t + \beta_{5,t}\Delta r_{t-1} + \beta_{6,t}(r_{t-1} - \bar{\rho}_t) + \bar{\rho}_t + a_t, \\ \bar{\pi}_t &= -\beta_{1,t}/(\beta_{2,t} + \beta_{6,t} - 1). \end{aligned}$$

tvp format	estimated $\bar{\beta}_i$ [2]						estimated $\bar{\pi}_t$	
	$\bar{\beta}_1$	$\bar{\beta}_2$	$\bar{\beta}_3$	$\bar{\beta}_4$	$\bar{\beta}_5$	$\bar{\beta}_6$	max	min
random walk intercept	.025 [.60]	.116 [.01]	-.067 [.09]	-.229 [.03]	.532 [.00]	.893 [.00]	-.10	-3.7
random walk coefficients	.052 [.77]	.132 [.01]	-.081 [.06]	-.240 [.08]	.521 [.00]	.879 [.00]	193	-207
stationary coefficients (var decomp %)	.017 [.90] 17	.120 [.01] 42	-.066 [.11] 1	-.242 [.03] 0	.523 [.00] 0	.891 [.00] 40	1.1	-9.0
random walk intercept	.148 [.00]	.076 [.07]	-.057 [.20]		.604 [.00]	.908 [.00]	10.7	6.1
random walk coefficients	.166 [.38]	.084 [.08]	-.058 [.17]		.584 [.00]	.899 [.00]	21.6	8.4
stationary coefficients (var decomp %)	.111 [.41] 23	.081 [.06] 37	-.048 [.24] 1		.606 [.00] 0	.908 [.00] 38	15.6	8.2
random walk intercept	.049 [.31]	.073 [.04]		-.208 [.04]	.551 [.00]	.920 [.00]	9.7	6.5
random walk coefficients	.070 [.61]	.078 [.01]		-.204 [.01]	.545 [.00]	.914 [.00]	287	- 16.8
stationary coefficients (var decomp %)	.045 [.74] 19	.075 [.04] 38		-.209 [.05] 0	.545 [.00] 0	.920 [.00] 42	14.8	6.7

1. sample 1970Q1-1979Q2; $r-$ avg federal funds rate in FOMC meeting-to-meeting intervals; π^k - GB annualized inflation forecasts, averaged over the forecast periods, h = -2, -1, 0,1.
2. $[\,.\,]$ - p-values; $\bar{\beta}_i-$ sample average of $\beta_{i,t}$ for random walk specifications.

Table 10: Federal Funds Rate Policy Rule,
Volcker/Greenspan sample[1]

$$r_t^* = \bar{\rho}_t + \bar{\pi}_t + c_{2,t}(\pi_t^k - \bar{\pi}_t) + c_{3,t}(u_{t+k} - \bar{u}_t) + c_{4,t}\Delta u_t,$$

$$r_t = (1-\beta_{6,t})r_t^* + \beta_{5,t}\Delta r_{t-1} + \beta_{6,t}r_{t-1} + a_t,$$
$$= \beta_{1,t} + \beta_{2,t}\pi_t^k + \beta_{3,t}(u_{t+k} - \bar{u}_t) + \beta_{4,t}\Delta u_t + \beta_{5,t}\Delta r_{t-1} + \beta_{6,t}(r_{t-1} - \bar{\rho}_t) + \bar{\rho}_t + a_t,$$

$$\bar{\pi}_t = -\beta_{1,t}/(\beta_{2,t} + \beta_{6,t} - 1).$$

tvp format	estimated $\bar{\beta}_i$ [2]						estimated $\bar{\pi}_t$	
	π^k - GB forecast average, h = 0,1; k = 1.							
	$\bar{\beta}_1$	$\bar{\beta}_2$	$\bar{\beta}_3$	$\bar{\beta}_4$	$\bar{\beta}_5$	$\bar{\beta}_6$	max	min
random walk	-..031	.129	-.060	-.262	.366	.877	7.9	-0.5
intercept	[.72]	[.01]	[.07]	[.02]	[.00]	[.00]		
random walk	-.029	.136	-.045	-.322	.367	.865	70.8	-91.3
coefficients	[.91]	[.20]	[.28]	[.46]	[.11]	[.00]		
stationary	-.041	.133	-.043	-.305	.375	.874	65.3	-90.1
coefficients	[.69]	[.01]	[.08]	[.01]	[.00]	[.00]		
(var decomp %)	10	35	0	0	0	55		
	π^k - GB forecast average, h = -2, -1, 0,1; k = 1.							
	$\bar{\beta}_1$	$\bar{\beta}_2$	$\bar{\beta}_3$	$\bar{\beta}_4$	$\bar{\beta}_5$	$\bar{\beta}_6$	max	min
random walk	-.159	.222	-.073	-.296	.364	.833	3.5	2.2
intercept	[.05]	[.00]	[.01]	[.01]	[.00]	[.00]		
random walk	-.170	.234	-.074	-.336	.377	.817	6.3	-31.9
coefficients	[.47]	[.04]	[.11]	[.43]	[.07]	[.00]		
stationary	-.154	.229	-.066	-.286	.406	.819	3.4	3.1
coefficients	[.20]	[.02]	[.03]	[.09]	[.00]	[.00]		
(var decomp %)	5	58	0	0	0	37		
	π^k - GB forecast average, h = 0,1,2,3; k = 3.							
	$\bar{\beta}_1$	$\bar{\beta}_2$	$\bar{\beta}_3$	$\bar{\beta}_4$	$\bar{\beta}_5$	$\bar{\beta}_6$	max	min
random walk	-.205	.214	-.050	-.237	.361	.845	4.0	2.7
intercept	[.02]	[.00]	[.08]	[.04]	[.00]	[.00]		
random walk	-.165	.203	-.046	-.285	.361	.838	69.9	-39.8
coefficients	[.49]	[.02]	[.23]	[.40]	[.07]	[.00]		
stationary	-.149	.194	-.049	-.273	.371	.846	4.0	3.5
coefficients	[.19]	[.00]	[.06]	[.03]	[.00]	[.00]		
(var decomp %)	14	37	1	0	0	48		

1. sample 1979Q3-1997Q4; $r-$ avg federal funds rate in FOMC meeting-to-meeting intervals; $\bar{u}_t-$ tvp average expectations.

2. [.] - p-values; $\bar{\beta}_i-$ sample average of $\beta_{i,t}$ for random walk specifications.

Table 11: Federal Funds Rate Policy Rule, Burns/Miller sample: money growth targeting, h = 0,1 [1]

$$
\begin{aligned}
r_t^* &= \bar{\rho}_t + \bar{\pi}_t + c_{2,t}(x_t^k - \bar{x}_t) + c_{3,t}(u_{t+1} - \bar{u}_t) + c_{4,t}\Delta u_t^k, \\
x_t^k - \bar{x}_t &= \pi_t^k - \bar{\pi}_t - a'\Delta u_t^k, \\
r_t &= (1-\beta_{6,t})r_t^* + \beta_{5,t}\Delta r_{t-1} + \beta_{6,t} r_{t-1} + a_t, \\
&= \beta_{1,t} + \beta_{2,t}x_t^k + \beta_{3,t}(u_{t+k} - \bar{u}_t) + \beta_{4,t}\Delta u_t^k + \beta_{5,t}\Delta r_{t-1} + \beta_{6,t}(r_{t-1} - \bar{\rho}_t) + \bar{\rho}_t + a_t, \\
\bar{\pi}_t &= -\beta_{1,t}/(\beta_{2,t} + \beta_{6,t} - 1).
\end{aligned}
$$

tvp format	estimated $\bar{\beta}_i$ [2]						estimated $\bar{\pi}_t$	
	$\bar{\beta}_1$	$\bar{\beta}_2$	$\bar{\beta}_3$	$\bar{\beta}_4$	$\bar{\beta}_5$	$\bar{\beta}_6$	max	min
random walk	.160	.024	-.021		.514	.955	8.5	6.3
intercept	[.00]	[.10]	[.53]		[.00]	[.00]		
random walk	.195	.024	-.029		.507	.952	9.2	7.4
coefficients	[.22]	[.21]	[.51]		[.00]	[.00]		
stationary	.139	.027	-.018		.508	.955	8.8	7.5
coefficients	[.27]	[.07]	[.59]		[.00]	[.00]		
(var decomp %)	37	10	2		0	50		
random walk	.091	.047		.059	.549	.940	7.7	5.8
intercept	[.07]	[.24]		[.53]	[.00]	[.00]		
random walk	.114	.050		.071	.545	.934	13.1	6.4
coefficients	[.52]	[.27]		[.55]	[.00]	[.00]		
stationary	.079	.052		.068	.542	.938	8.7	6.6
coefficients	[.58]	[.20]		[.48]	[.00]	[.00]		
(var decomp %)	22	34		1	0	43		
random walk	.143	.023			.530	.955	7.2	5.6
intercept	[.00]	[.12]			[.00]	[.00]		
random walk	.167	.022			.530	.954	7.3	6.4
coefficients	[.28]	[.20]			[.00]	[.00]		
stationary	.129	.025			.523	.956	7.2	6.4
coefficients	[.30]	[.08]			[.00]	[.00]		
(var decomp %)	40	7			0	54		

1. sample 1970Q1-1979Q2; $r-$ avg federal funds rate in FOMC meeting-to-meeting intervals; $\pi^k, \Delta u^k$ - GB annualized forecasts, averaged over the forecast periods, $h = 0, 1$.
2. $[\,.\,]$ - p-values; $\bar{\beta}_i-$ sample average of $\beta_{i,t}$ for random walk specifications.

Table 12: Federal Funds Rate Policy Rule, Burns/Miller sample: money growth targeting, h = -2, -1, 0,1 [1]

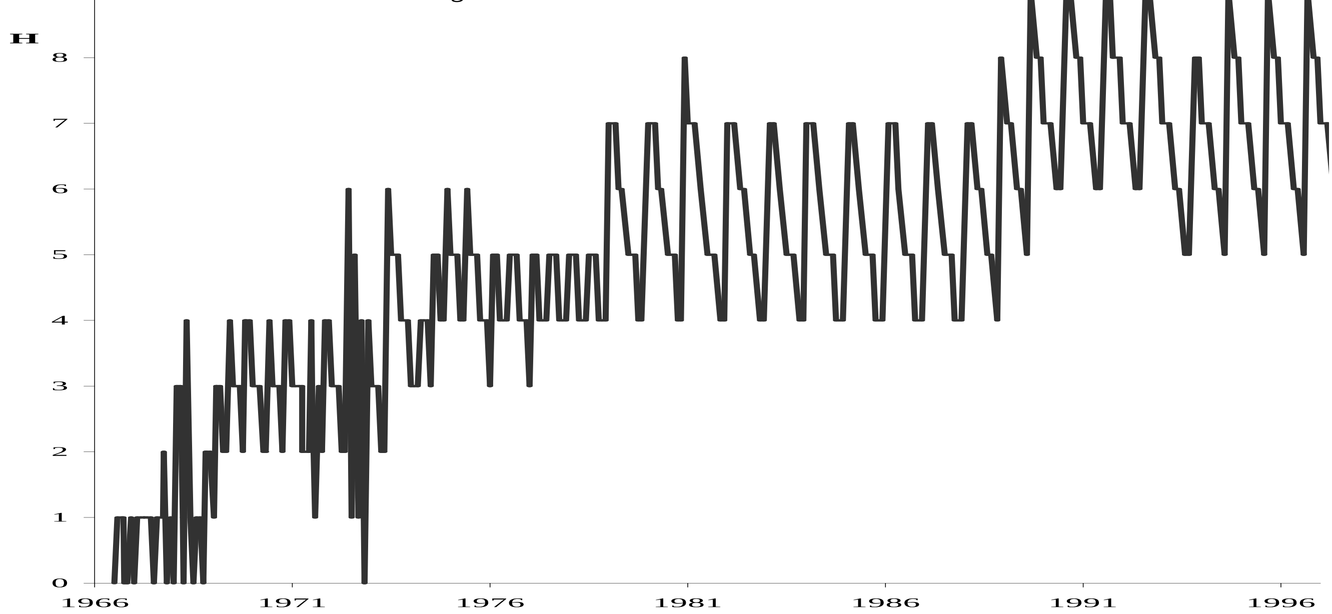
$$
\begin{aligned}
r_t^* &= \bar{\rho}_t + \bar{\pi}_t + c_{2,t}(x_t^k - \bar{x}_t) + c_{3,t}(u_{t+1} - \bar{u}_t) + c_{4,t}\Delta u_t^k, \\
x_t^k - \bar{x}_t &= \pi_t^k - \bar{\pi}_t - a'\Delta u_t^k, \\
r_t &= (1-\beta_{6,t})r_t^* + \beta_{5,t}\Delta r_{t-1} + \beta_{6,t}r_{t-1} + a_t, \\
&= \beta_{1,t} + \beta_{2,t}x_t^k + \beta_{3,t}(u_{t+k} - \bar{u}_t) + \beta_{4,t}\Delta u_t^k + \beta_{5,t}\Delta r_{t-1} + \beta_{6,t}(r_{t-1} - \bar{\rho}_t) + \bar{\rho}_t + a_t, \\
\bar{\pi}_t &= -\beta_{1,t}/(\beta_{2,t} + \beta_{6,t} - 1).
\end{aligned}
$$

tvp format	estimated $\bar{\beta}_i$ [2]						estimated $\bar{\pi}_t$	
	$\bar{\beta}_1$	$\bar{\beta}_2$	$\bar{\beta}_3$	$\bar{\beta}_4$	$\bar{\beta}_5$	$\bar{\beta}_6$	max	min
random walk	.156	.037	-.008		.518	.942	7.5	6.3
intercept	[.00]	[.03]	[.80]		[.00]	[.00]		
random walk	.189	.039	-.018		.499	.936	8.5	7.0
coefficients	[.23]	[.07]	[.67]		[.00]	[.00]		
stationary	.149	.040	-.009		.509	.940	7.8	6.8
coefficients	[.21]	[.02]	[.78]		[.00]	[.00]		
(var decomp %)	30	11	2		0	56		
random walk	.024	.093		.114	.557	.906	27.1	9.4
intercept	[.61]	[.02]		[.12]	[.00]	[.00]		
random walk	.040	.102		.130	.540	.894	360	-27
coefficients	[.82]	[.03]		[.19]	[.00]	[.00]		
stationary	.037	.092		.114	.545	.904	118	7.4
coefficients	[.78]	[.02]		[.13]	[.00]	[.00]		
(var decomp %)	16	33		0	0	51		
random walk	.146	.037			.523	.941	7.1	6.1
intercept	[.00]	[.03]			[.00]	[.00]		
random walk	.169	.038			.511	.937	7.6	6.4
coefficients	[.27]	[.07]			[.00]	[.00]		
stationary	.142	.038			.515	.940	7.2	6.5
coefficients	[.21]	[.02]			[.00]	[.00]		
(var decomp %)	32	10			0	58		

1. sample 1970Q1-1979Q2; $r-$ avg federal funds rate in FOMC meeting-to-meeting intervals; $\pi^k, \Delta u^k$ - GB annualized forecasts, averaged over the forecast periods, $h = -2, -1, 0, 1$.

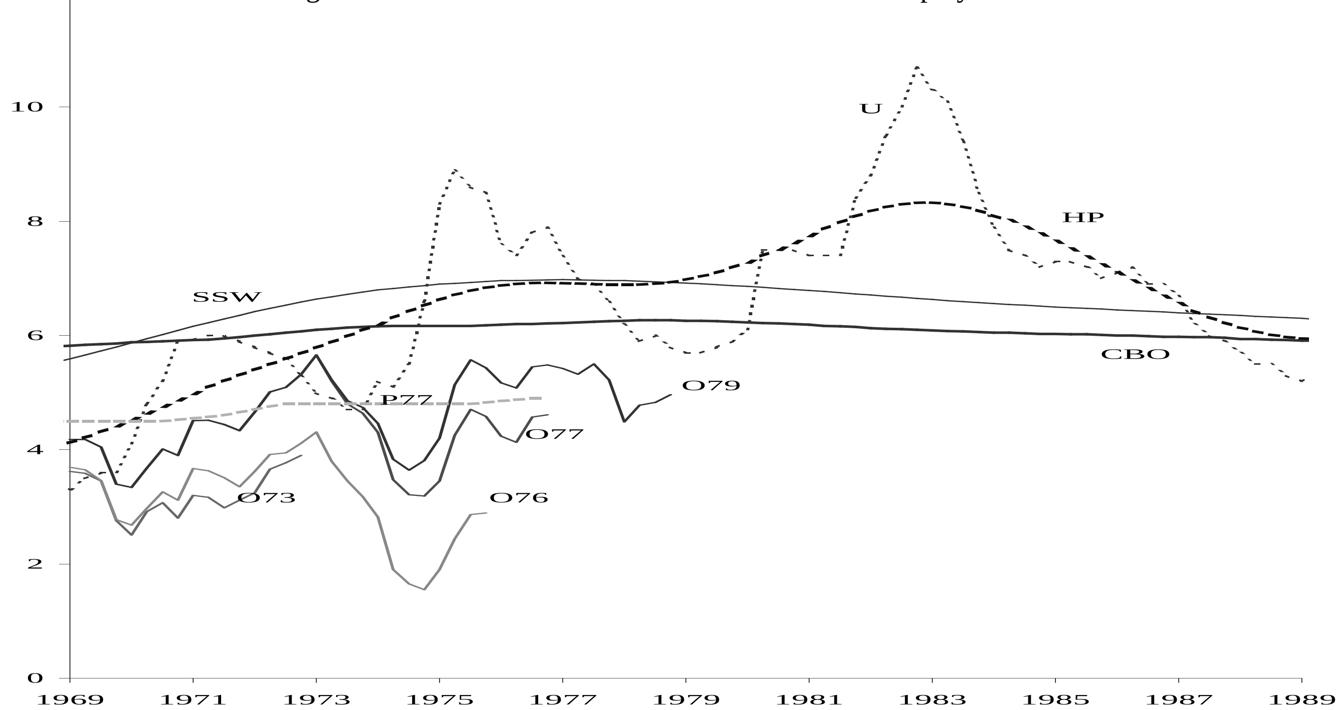
2. $[\,.\,]$ - p-values; $\bar{\beta}_i-$ sample average of $\beta_{i,t}$ for random walk specifications.

Figure 1: Greenbook forecast horizons [1]



1. H - horizon of Greenbook forecast, $h = 0, 1, \ldots, H$.

Figure 2: Alternative Natural Rate Estimates for Unemployment [1]



1. Real-time civilian unemployment: U.
Retrospective natural rates: CBO, Congressional Budget Office (2004); SSW, Staiger, Stock, & Watson (1977).
Real-time natural rates: HP, Hodrick-Prescott filter; P77, Perry (1977); O73, O76, O77, O79, calculated from Orphanides (2003a), see text.

Figure 3: Greenbook One-Quarter Forecast Errors of Inflation

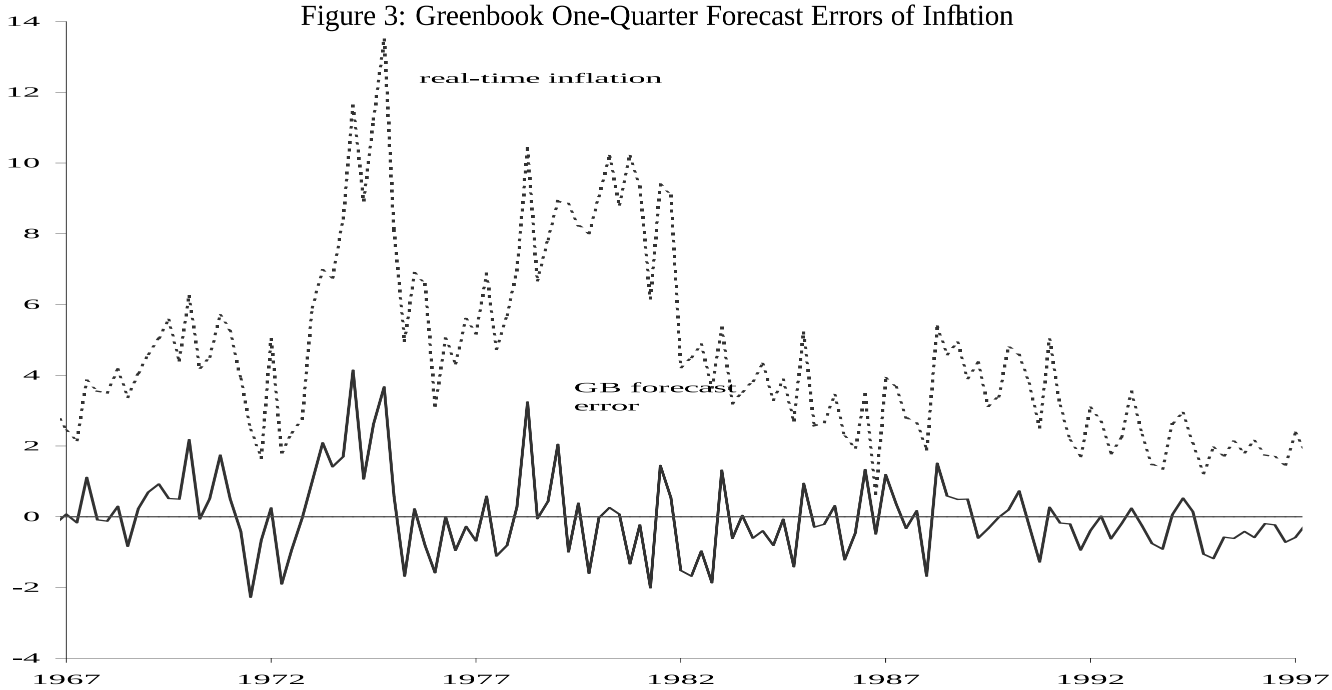
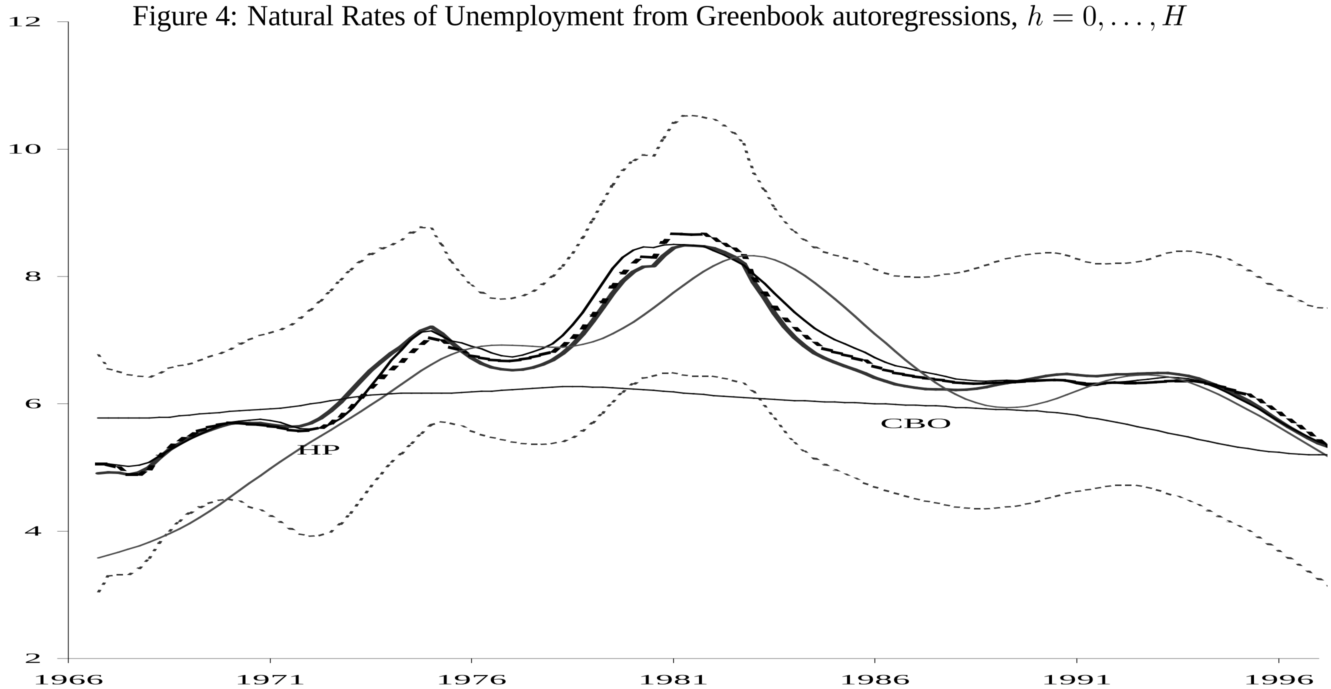
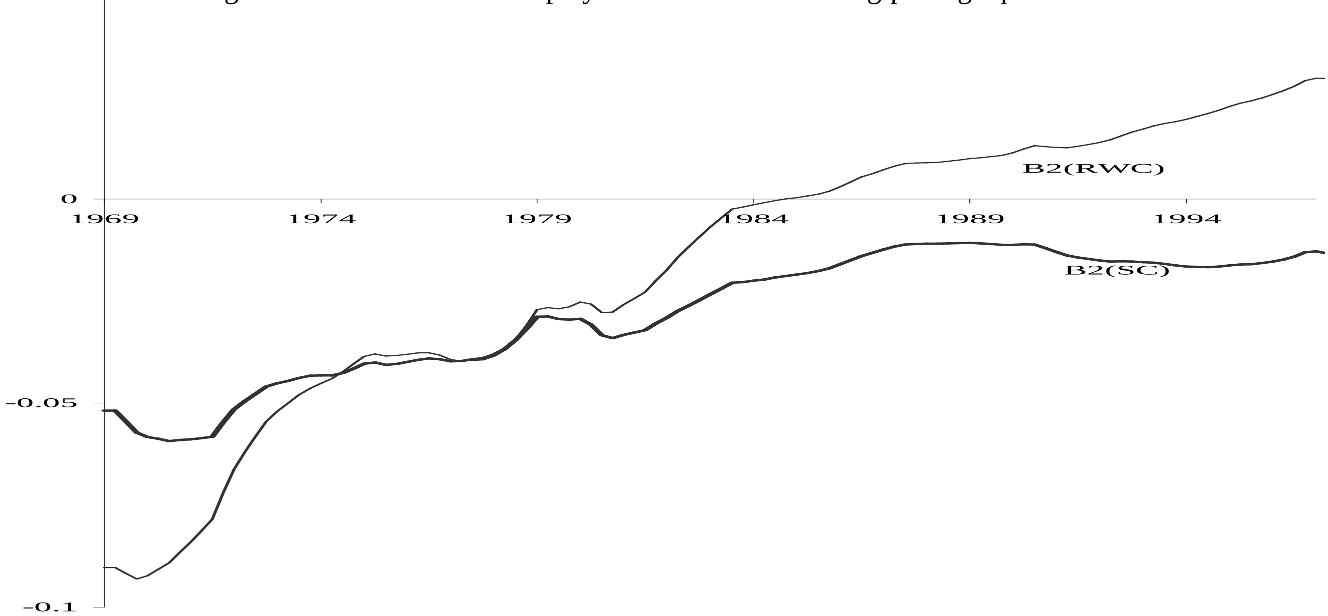


Figure 4: Natural Rates of Unemployment from Greenbook autoregressions, $h = 0, \ldots, H$



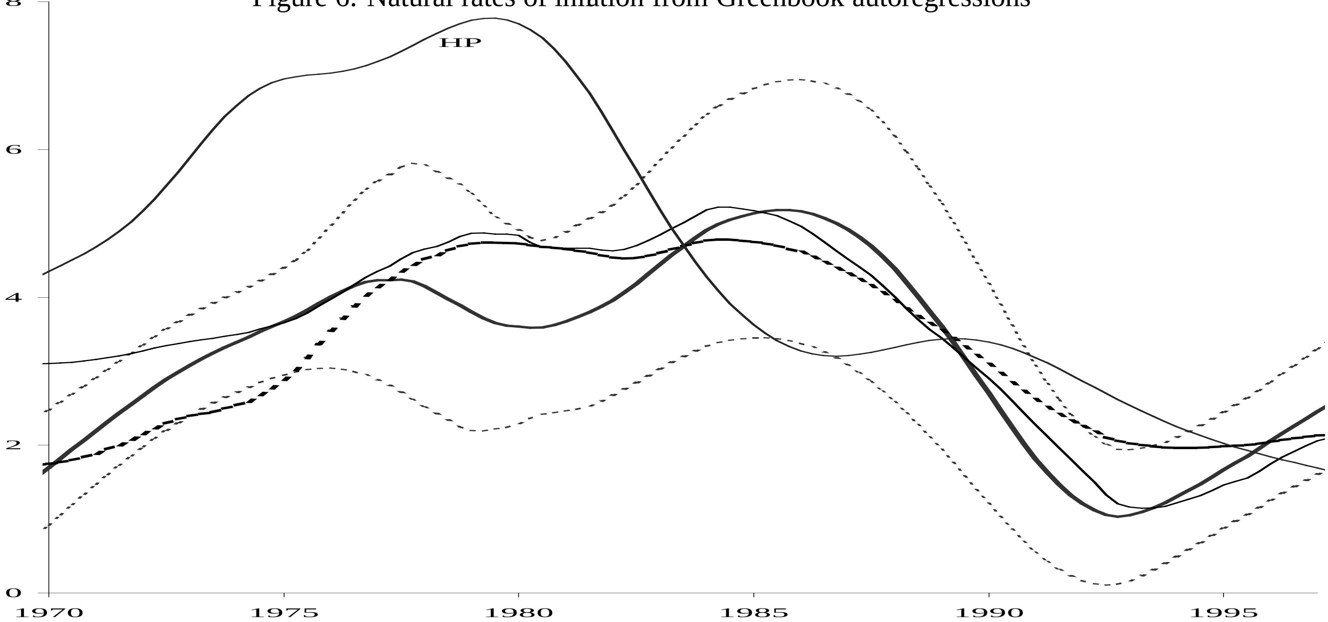
1. Unemployment autoregressions described in top panel of Table 2.
Thin solid line: random walk intercept estimator, RWI;
thick dotted line: tvp random walk coefficients estimator, RWC;
thick solid line: tvp stationary coefficients estimator, SC.
Thin dotted lines are 70% confidence intervals of SC estimator.
CBO and HP estimates of natural rates described in text.

Figure 5: Coefficient of unemployment in forward-looking pricing equations [1]



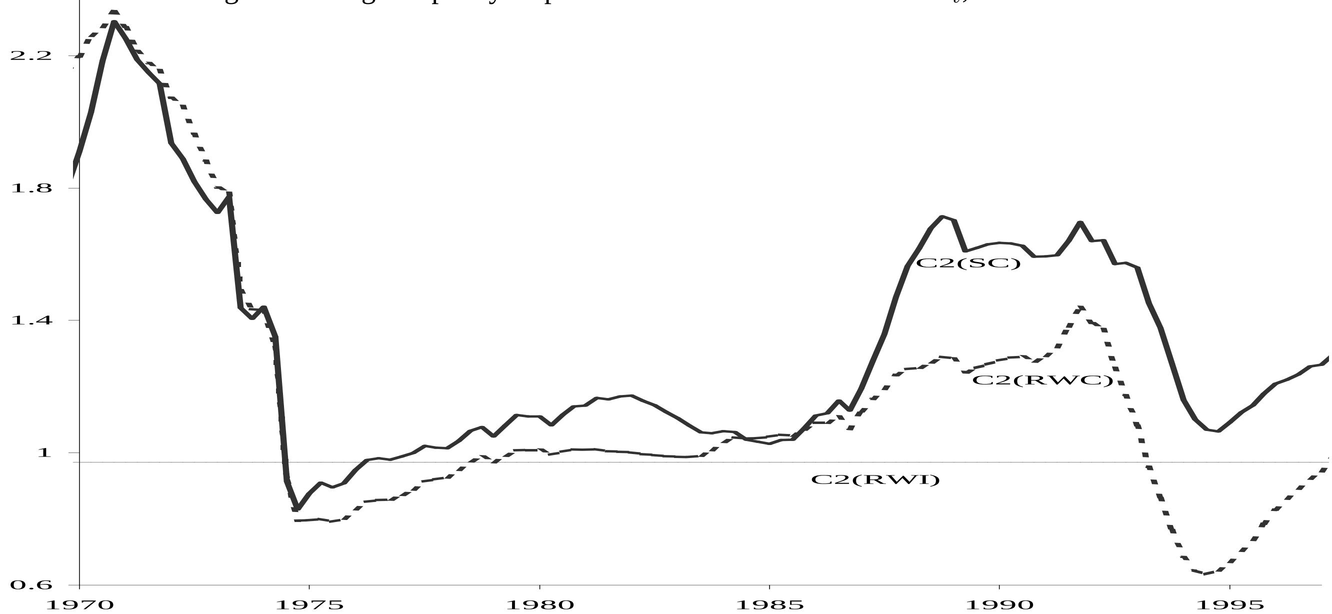
1. Coefficients from estimators in the top panel of Table 4.
   B2(RWC) - $\beta_{2,t}$ from random walk coefficients estimator, RWC.
   B2(SC) - $\beta_{2,t}$ from stationary coefficients estimator, SC.

Figure 6: Natural rates of inflation from Greenbook autoregressions [1]



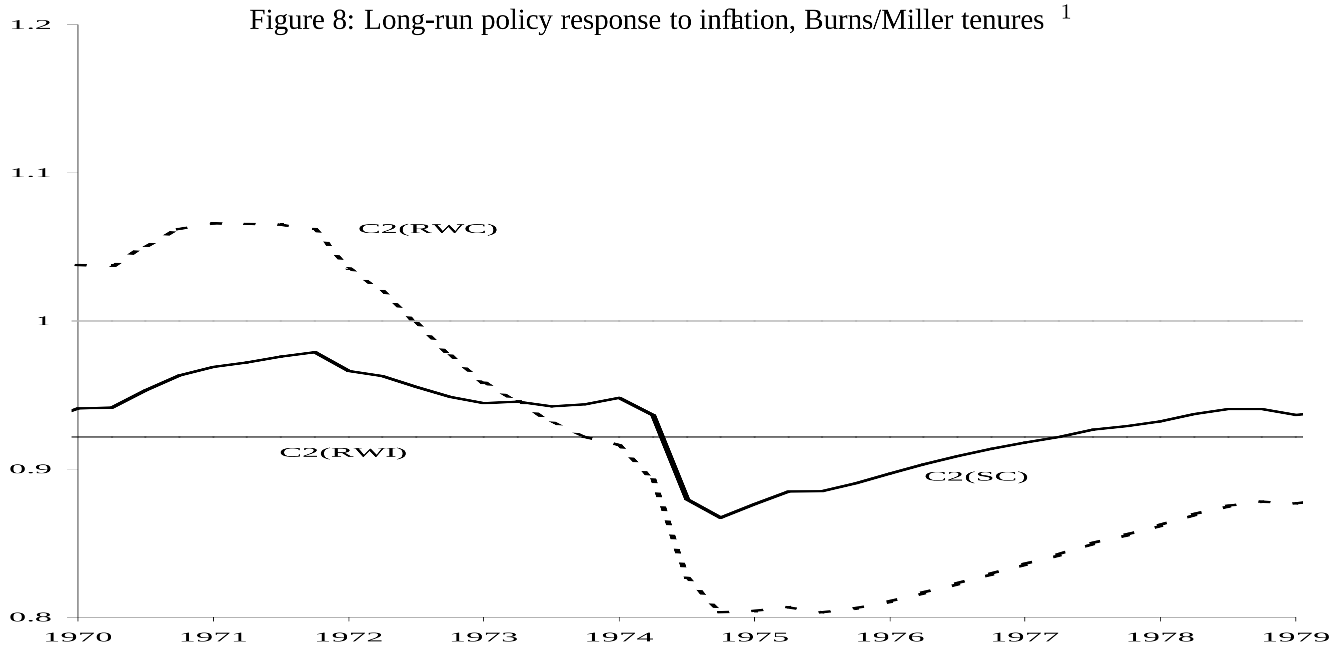
1. Inflation autoregressions described in Table 6.
   Thin solid line: random walk intercept estimator, RWI;
   thick dotted line: tvp random walk coefficients estimator, RWC;
   thick solid line: tvp stationary coefficients estimator, SC.
   Thin dotted lines are 70% confidence intervals of SC estimator. HP estimate discussed in text.

Figure 7: Long-run policy response to inflation conditioned on $\bar{u}_t$, 1969-1997 [1]



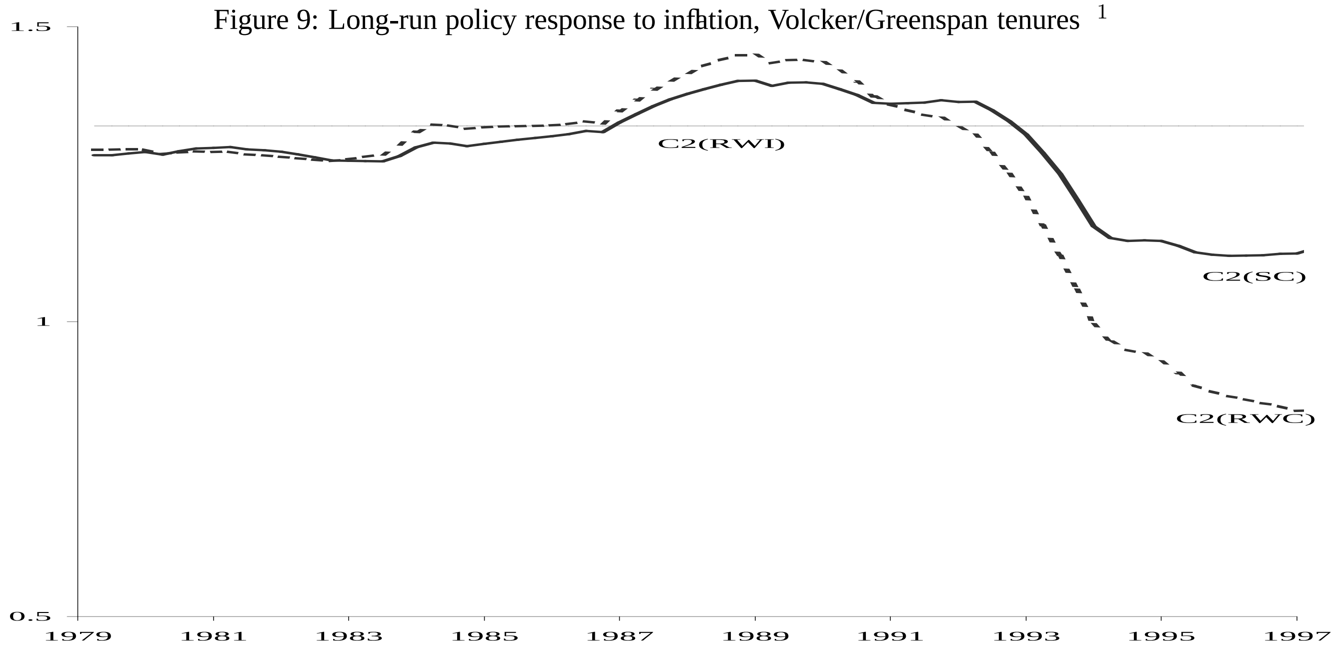
1. Coefficients from estimators in top panel of Table 7, using the preferred natural rate, $\bar{u}_t$.
   C2(RWI) - $c_{2,t}$ from random walk intercept estimator, RWI.
   C2(RWC) - $c_{2,t}$ from random walk coefficients estimator, RWC.
   C2(SC) - $c_{2,t}$ from stationary coefficients estimator, SC.

Figure 8: Long-run policy response to inflation, Burns/Miller tenures [1]



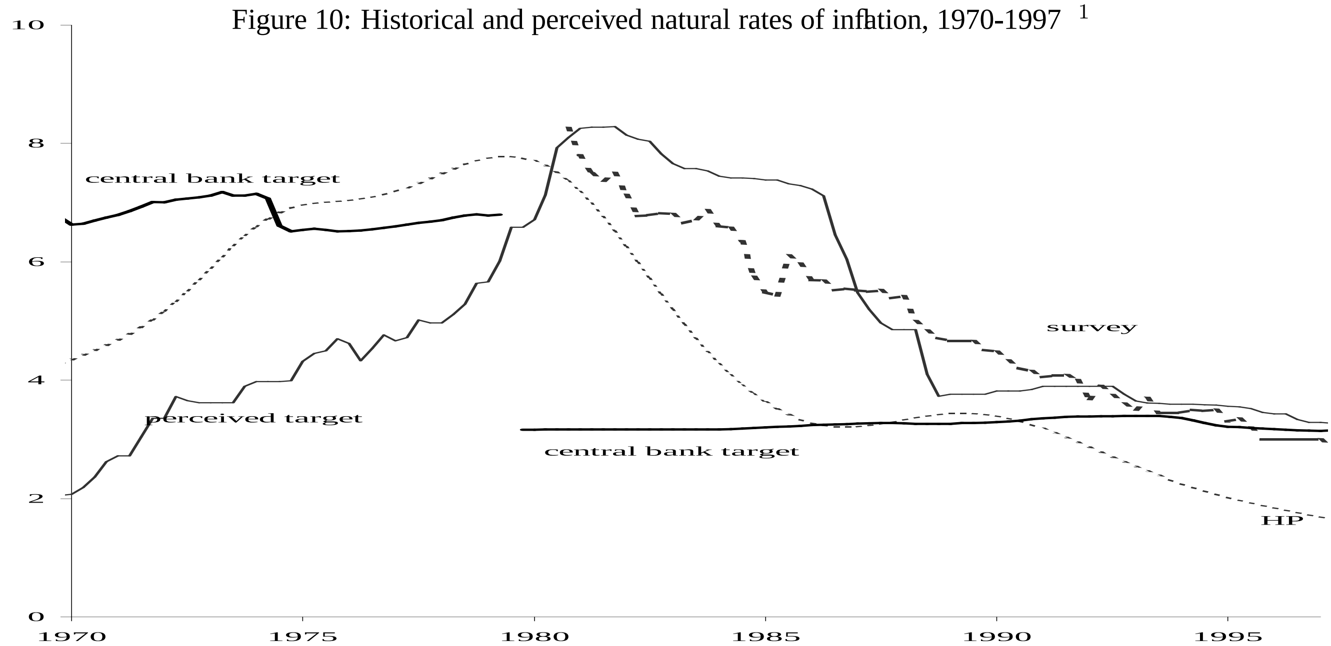
1. Coefficients from estimators in the bottom panel of Table 9.
   C2(RWI) - $c_{2,t}$ from random walk intercept estimator, RWI.
   C2(RWC) - $c_{2,t}$ from random walk coefficients estimator, RWC.
   C2(SC) - $c_{2,t}$ from stationary coefficients estimator, SC.

Figure 9: Long-run policy response to inflation, Volcker/Greenspan tenures [1]



1. Coefficients from estimators in middle panel of Table 10.
   C2(RWI) - $c_{2,t}$ from random walk intercept estimator, RWI.
   C2(RWC) - $c_{2,t}$ from random walk coefficients estimator, RWC.
   C2(SC) - $c_{2,t}$ from stationary coefficients estimator, SC.

Figure 10: Historical and perceived natural rates of inflation, 1970-1997 [1]



1. Central bank target - $\bar{\pi}_t$ implied by SC estimator: bottom panel of Table 12 for Burns/Miller sample.
   and middle panel of Table 10 for Volcker/Greenspan sample.
   Perceived target - private sector perception, $\bar{\pi}^p_t$, from Kozicki and Tinsley (2001a).
   Survey - Hoey survey of 5-10 year expected inflation (see text).
   HP - HP filter of real-time inflation.

Figure 11: Federal funds rate and FOMC tolerance ranges, Burns/Miller tenures

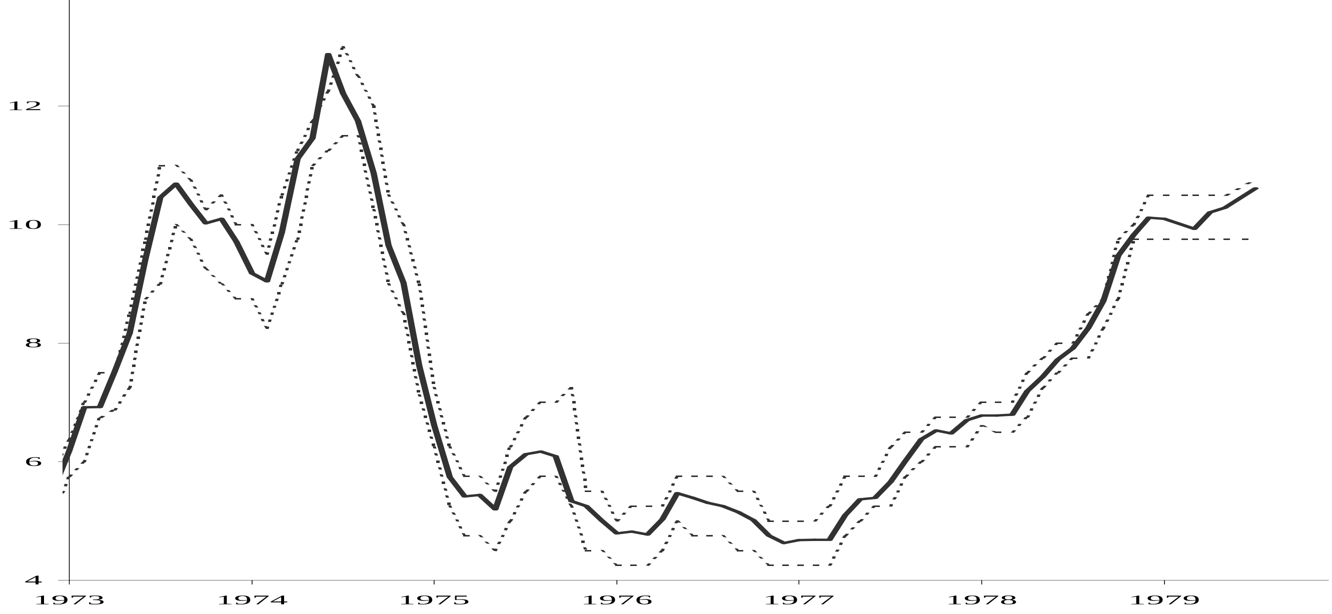
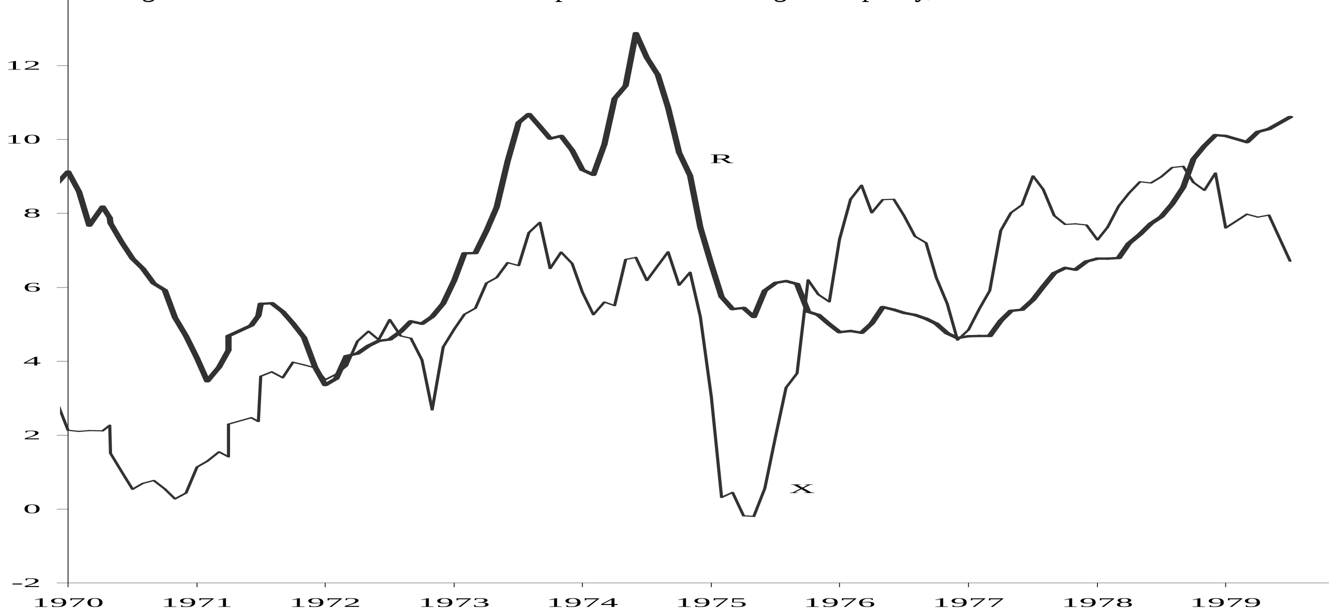


Figure 12: Federal funds rate and the predicted nominal growth proxy, Burns/Miller tenures [1]



1. R - Federal funds rate; X - 4-qtr avg of the predicted nominal growth proxy, using Greenbook forecasts for $h = -2, -1, 0, 1$; (see text).