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**EVALUATING MCCALLUM'S RULE  
WHEN MONETARY POLICY MATTERS**

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## **Evaluating McCallum's Rule When Monetary Policy Matters**

### **Abstract**

This paper provides new evidence on the usefulness of McCallum's proposed rule for monetary policy. The rule targets nominal GDP using the monetary base as the instrument. We analyze the rule using three very different economic models to see if the rule works well in different environments. Our results suggest that while the rule leads to lower inflation than there has been over the last 30 years, instability problems suggest that the rule should be modified to feed back on the growth rate of nominal GDP rather than the level.

## EVALUATING MCCALLUM'S RULE WHEN MONETARY POLICY MATTERS

### I. Introduction

The standard approach used by economists to discuss monetary policy is to write down a model of the economy, demonstrate what optimal monetary policy is in the model, and show how different the optimal policy is from the policy that was actually in place. Since each economist engaged in such a task typically comes up with a unique model, we have a large number of views of optimal monetary policy, all of which are model-specific. After decades of following this strategy, it's time for us to admit that it isn't working. Fundamentally, macroeconomists disagree about the forces that drive the economy, and they are unlikely to ever discover the "true" model. Thus, they are unlikely to find "the" optimal rule on which to base monetary policy. Just as with research on finding a cure for the common cold, the expected payoff to continued research on discovering the right model has become very small.

This lack of a generally accepted model creates a key tension within the Federal Reserve since neither policymakers nor economic staff at the Fed share a common theory of macroeconomics. Thus, there are different views of what monetary policy ought to do at any point in time given the current state of the economy. As a result, policy outcomes depend on consensus-building, for it is seldom the case that Keynesian, monetarist, new Keynesian, and new classical models point in the same direction.

McCallum (1987, 1988, 1990, 1993, 1994) suggests a new approach. He has proposed a specific rule for the Federal Reserve to follow in setting monetary policy, which he developed outside the confines of a single model, and which he suggests would work well in many different economic models. The rule would have the Fed target the level of nominal

GDP using the monetary base as its instrument. Using a variety of empirical models, McCallum has shown that had the rule been in place instead of the actual discretionary monetary policy, nominal GDP growth would have been substantially lower over the past 30 years, implying a lower average rate of inflation. These results have been verified in additional models by Judd and Motley (1991, 1992, 1993).<sup>1</sup> If McCallum's proposed rule works well in all of these types of models, policymakers or economists of any theoretical predisposition could subscribe to the rule.

This paper addresses three aspects of McCallum's proposed rule: (1) it expands the set of models used to evaluate McCallum's rule; (2) it shows how impulse responses can be used to evaluate the stabilization properties of McCallum's rule in our models; and (3) it provides a more detailed accounting of how the rule affects the endogenous variables in our models. Following McCallum and Judd-Motley, we also use our models to conduct stochastic simulations, with McCallum's rule determining the monetary-policy response to disturbances.

One problem with the studies of McCallum and Judd-Motley is that they draw upon economic models designed solely for the purpose of evaluating the rule; in particular, in their structural models they usually estimate equations relating the monetary base directly to nominal GDP. The main idea of this article is to expand the set of economic models on which McCallum's rule has been tested. In particular, we examine economic models developed for purposes other than testing McCallum's rule, in which the relationship between the monetary

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<sup>1</sup>However, the results have been challenged by Hess, Small, and Brayton (1992). Also, a number of variations on McCallum's rule have been tested, including the use of the federal funds rate instead of the monetary base as the policy instrument.

base and nominal GDP is less direct. If the rule performs well in these models, such evidence will be more convincing than finding that the rule works well in models designed specifically to test it.

The second innovation of our paper is to use impulse responses to analyze the problem of model instability. McCallum, Judd-Motley, and others working in this literature have found cases where either a target variable (like nominal GDP) or the instrument variable (the monetary base) suffer from explosive oscillations. As we show below, it isn't always clear how to identify this instability. We propose looking at impulse responses.

Finally, we evaluate the rule over a larger number of dimensions than previous researchers have done. McCallum has argued that economists do not yet have an adequate understanding of the breakdown of nominal GDP into prices and real GDP. Thus, he proposes analyzing his rule by simulating its effect on the target variable, nominal GDP. While we are sympathetic to McCallum's view, we also believe that policymakers have a particular interest in the behavior of prices and real output. Thus, in our evaluation, we report how the rule affects inflation and real output (using a battery of summary statistics), as well as how it affects McCallum's preferred variable, nominal GDP.

The models we use are all models in which monetary policy has real effects. We don't examine real-business-cycle models or rational-expectations models because the real effects of monetary policy in those models tend to be nonexistent or very small. As such, McCallum's rule no doubt works quite well in maintaining a low rate of inflation with no significant consequences for real output. So the question we're really seeking to answer in this paper is,

in the class of models in which monetary policy potentially has real effects, how well does McCallum's rule work?

The Lucas critique can be directed powerfully to this research. Following previous literature, we conduct counterfactual policy experiments while leaving behavioral equations unchanged, which is precisely what Lucas warned about. There is no defense against this critique except to build models that can deal fully with behavioral changes in response to policy changes. None exist yet, though much research is under way on new classical models with money. So we take our results as preliminary, until more complete macroeconomic models in which money matters are developed.

In the next section we describe McCallum's rule and the three models we use to examine it. The following section introduces the stochastic simulation technique we use to evaluate the rule and shows the results for each model. Then we discuss the issue of stability and how varying the monetary response factor in McCallum's rule may be necessary.

## II. McCallum's Rule and Our Models

McCallum's rule is specified by the equation:

$$\Delta B_t = (\Delta P_t^* + \Delta Y_t^*) - \Delta \bar{V}B_t + \lambda(X_{t-1}^* - X_{t-1}), \quad (1)$$

where all variables are in logarithms,  $B_t$  is the monetary base at time  $t$ ,  $P$  is the price level,  $Y$  is real GDP,  $\Delta \bar{V}B$  is an estimate of the long-run growth rate of monetary base velocity (equal to nominal GDP divided by the monetary base),  $\lambda$  is a parameter that we call the monetary response factor,  $X$  is the log of nominal GDP, and an asterisk (\*) denotes either the targeted

value of a variable or a desired rate of growth. The growth of the monetary base is determined by the three terms on the right-hand side of equation (1). The first term sets the monetary base growth rate equal to the desired rate of inflation ( $\Delta P^*$ ) plus the rate of growth of potential real GDP ( $\Delta Y^*$ ). The second term on the right-hand side of equation (1) is the growth rate of monetary-base velocity, which McCallum estimates as a 16-quarter moving average of monetary-base velocity. This term helps to prevent the price level from drifting in response to a permanent shock to money demand. With velocity growing at its steady-state rate and the level of nominal GDP equal to target, the rule forces the rate of inflation to  $\Delta P^*$ , assuming that monetary policy is neutral in the long run.

The last term on the right-hand side of equation (1) is the most important term for the stabilization properties of McCallum's rule. It allows the monetary authority to adjust monetary base growth whenever nominal GDP differs from its target. For example, when nominal GDP is below target, the Fed should temporarily increase monetary base growth. Following McCallum, we define the target path for nominal GDP recursively by  $X_t^* = X_{t-1}^* + (\Delta Y^* + \Delta P^*)$ , with  $X_0^* = X_0$ .

Our philosophy rests on choosing models that reflect a variety of beliefs about how the economy works. Thus, we choose to examine a Keynesian model, a reduced-form model, and a structural VAR model. If McCallum's rule works well in all three models, then all policymakers should be interested in the rule; if it works only in certain types of models, then only policymakers who believe in the theory underlying such a model are likely to be interested in the rule. As stated earlier, an interesting feature of this paper is that we borrow these models from the existing literature, rather than drawing up new models. In general,

we've kept the models as close to their original form as we could, though we've had to adapt them slightly to enable them to handle McCallum's rule.

### A Keynesian Model

Ben Friedman (1984) developed a complete Keynesian model of the economy. The following equations describe our version of the model, which we've estimated on quarterly U.S. data from 1959Q1 to 1993Q2 (the sample was determined by data availability). The equations are estimated using two-stage least squares, just as Friedman used in his original model. There is a correction for serial correlation, following the method of Fair (1970, 1984).<sup>2</sup> The results of the estimation are:

$$IS: \quad \Delta \hat{Y}_t = 1.35 + 0.542\Delta Y_{t-1} + 0.0527\Delta E_t - 1.98\Delta RBAA_t - 0.0338\Delta PIM_{t-1} \\ (3.33) \quad (7.07) \quad (1.26) \quad (1.85) \quad (1.07) \quad (2) \\ \hat{\rho} = -0.282 \quad \bar{R}^2 = 0.08 \\ (2.28)$$

$$AS: \quad \Delta \hat{P}_t = 0.275\Delta P_{t-1} + 0.267\Delta P_{t-2} + 0.291\Delta P_{t-3} + 0.094\Delta P_{t-4} \\ (3.24) \quad (3.10) \quad (3.41) \quad (1.14) \\ + 0.0546\Delta PIM_{t-1} + 0.0850[(Y_{t-1} - Y'_{t-1}) - (Y_{t-2} - Y'_{t-2})] \\ (4.18) \quad (2.50) \quad (3) \\ \bar{R}^2 = 0.72$$

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<sup>2</sup>As instruments, we use the set of instruments required by Fair, as well as other predetermined variables in the system.



$$\begin{aligned}
 MD: \quad \Delta \hat{RM}2_t &= 0.783 \Delta RM2_{t-1} + 0.143 \Delta Y_t - 2.19 \Delta RTB03_t \\
 &\quad (8.92) \qquad (1.26) \qquad (4.63) \\
 \hat{\rho} &= -0.275 \qquad \bar{R}^2 = 0.41 \qquad RM2_t = M2_t - P_t \\
 &\quad (2.51)
 \end{aligned} \tag{4}$$

$$\begin{aligned}
 MS: \quad \Delta M2_t &= -0.211 \Delta M2_{t-1} + 1.17 \Delta B_t - 0.261 \Delta RTB03_t \\
 &\quad (2.16) \qquad (7.37) \qquad (0.71) \\
 \hat{\rho} &= 0.817 \qquad \bar{R}^2 = 0.39 \\
 &\quad (13.3)
 \end{aligned} \tag{5}$$

$$\begin{aligned}
 TS: \quad RBAA_t &= 0.215 + 0.867 RBAA_{t-1} + 0.264 RTB03_t - 0.097 RTB03_{t-1} \\
 &\quad (1.73) \quad (40.8) \qquad (4.64) \qquad (1.80) \\
 \hat{\rho} &= 0.336 \qquad \bar{R}^2 = 0.99 \\
 &\quad (3.61)
 \end{aligned} \tag{6}$$

In all the regressions here and later in the paper, the terms in parentheses are the absolute values of the t-statistics, and  $\hat{\rho}$  is the first-order autocorrelation coefficient. Further, all variables, except interest rates, are in logarithms, and all growth rates are expressed in annualized terms.

Equation (2) is the *IS* curve, which relates the growth rate of real GDP (*Y*) to its own lag, the growth rate of real cyclically adjusted federal government expenditures (*E*), the change in the interest rate on Moody's BAA-rated corporate bonds (*RBAA*), and the change in the implicit import price deflator (*PIM*). Equation (3) is an aggregate supply curve, which indicates that the current inflation rate ( $\Delta P$ ) depends on its value over the past four quarters, lagged growth of import prices, and the change in the real GDP gap.<sup>3</sup> Equation (4) is a

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<sup>3</sup>To be consistent with the potential GDP series that we use elsewhere, equation (3) is slightly different from that in Friedman's original model. We replace the lagged growth rate

money-demand curve, relating the growth in real money demand ( $\Delta RM2$ ) to its own lag, the growth of income, and the change in the interest rate on three-month T-bills ( $RTB03$ ).

Equation (5) represents the nominal supply of money ( $M2$ ), which is determined by its own lagged growth rate, the growth rate of the monetary base ( $B$ ), and the change in the three-month T-bill interest rate. Finally, equation (6) is a term-structure equation relating the interest rate on BAA corporate bonds to its lagged value, and the current and lagged values of the three-month T-bill interest rate. Thus this model represents a Keynesian, IS-LM, aggregate supply-aggregate demand model.

The model's estimates are generally consistent with the theoretical IS-LM model. Most of the variables used in the model have statistically significant coefficients with signs that accord with theory.

### **A Reduced-Form Model**

Herb Taylor (1992) developed a restricted reduced-form model, which he called PSTAR+, for use in aiding monetary policy decisions. The model is based on two main hypotheses: (1) a theory developed by Laurent (1988) that the spread between the federal funds interest rate and long-term interest rates is closely related to subsequent output growth; and (2) the  $P^*$  (pronounced P-star) model developed by Hallman, Porter, and Small (1991).

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of output in the original model with lagged growth in the GDP gap. This requires us to specify a path for potential GDP. There are many alternatives one could choose from; we choose to use the potential GDP series developed at the Federal Reserve Board for use in the  $P^*$  model (see Hallman, Porter, and Small (1991)). In addition, to eliminate a problem with serial correlation, we add an additional three lags of inflation to equation (3).

The  $P^*$  model predicts future inflation using the monetarist theory that, in the long run, the price level is proportional to the M2 measure of the money supply.

The following equations describe the long-term relationships in the model:

$$Y_t = Y_t^* + z_t^Y \quad (7)$$

$$V2_t = V2^* + z_t^V \quad (8)$$

$$P_t = P_t^* + z_t^P \quad (9)$$

$$RTB10_t = 2.337 + \Delta P_t - 1.132D_{65} - 0.734D_{74} + 5.261D_{80} - 1.501D_{90} + z_t^{RL} \quad (10)$$

$$RFF_t = -0.692 + RTB10_t + z_t^{RS} \quad (11)$$

Equations (7) to (11) suggest that the logs of real GDP ( $Y$ ), M2 velocity ( $V2$ ), and the price level ( $P$ ) all deviate from their equilibrium levels by the amount of a random shock. The term  $Y^*$  is the log of potential output, the same variable used in the Keynesian model described in the previous section. The model asserts that long-run M2 velocity is constant, so we take  $V2^*$  to be the log of the mean value of velocity over the period from 1959Q1 to 1990Q4;

$V2^* = 0.495$ .<sup>4</sup> Finally,  $P^*$  itself is just the log of the price level consistent with constant velocity, output at its potential level, and the current money supply:

$$P_t^* \equiv M2_t + V2^* - Y_t^* \quad (12)$$

Equation (10) suggests that the interest rate on 10-year Treasury bonds ( $RTB10$ ) is equal to a constant plus the rate of inflation ( $\Delta P$ ) plus dummy terms representing breaks in the real interest rate series in 1965Q3, 1974Q1, 1980Q2, and 1990Q2. The inclusion of the inflation rate means the equation is consistent with a constant long-run equilibrium real interest rate. Following Taylor, the dummy variables correspond to breaks in the potential real GDP series. Finally, equation (11) suggests that the term structure has a fixed slope in the long run between the federal funds rate ( $RFF$ ) and the 10-year T-bond interest rate.

The deviations of these variables from their long-run values are thought to have an impact on the short-run values of the variables. The short run is modeled by the following equations:

$$\Delta \hat{Y}_t - \Delta Y_t^* = - 16.54z_{t-1}^Y - 40.54z_{t-1}^V - 0.768z_{t-2}^{RS} + 0.706\Delta RTB10_{t-1} + 0.198\Delta RTB10_{t-3} \quad (13)$$

(2.28)      (5.19)      (5.80)      (1.55)      (0.57)

$$\bar{R}^2 = 0.37$$

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<sup>4</sup>We estimate  $V2^*$  over the period 1959Q1 to 1990Q4 to get the same value for velocity as in Hallman, Porter, and Small (1991). The results aren't affected at all by this choice, as opposed to estimating velocity over the entire sample period from 1959Q1 to 1993Q2.

$$\begin{aligned}
\Delta \hat{V}_t^2 = & -33.54z_{t-1}^V + 1.326\Delta RFF_t + 0.737\Delta RFF_{t-1} + 2.125\Delta RTB10_{t-1} \\
& (3.35) \quad (6.87) \quad (3.21) \quad (3.62) \\
& + 0.954\Delta RTB10_{t-2} - 0.141(\Delta Y_{t-1} - \Delta Y_{t-1}^*) + 0.770DUMTIME_t \\
& (2.20) \quad (2.28) \quad (5.75)
\end{aligned} \tag{14}$$

$$\bar{R}^2 = 0.41$$

$$\begin{aligned}
\Delta \hat{\pi}_t = & -10.34z_{t-1}^P + 0.192z_{t-1}^{RL} - 0.544\Delta \pi_{t-1} - 0.198\Delta \pi_{t-2} \\
& (3.96) \quad (2.32) \quad (6.00) \quad (2.62) \\
& - 0.0363\Delta V2_{t-2} + 0.00591\Delta POIL_{t-2} \\
& (1.47) \quad (2.67)
\end{aligned} \tag{15}$$

$$\bar{R}^2 = 0.39$$

$$\begin{aligned}
\Delta RTB10_t = & -0.0480z_{t-1}^{RL} + 0.0684z_{t-1}^{RS} + 0.218\Delta RFF_t \\
& (2.27) \quad (3.27) \quad (7.23)
\end{aligned} \tag{16}$$

$$\bar{R}^2 = 0.43$$

$$\begin{aligned}
\Delta \hat{RFF}_t = & 14.18z_{t-1}^Y - 0.185z_{t-1}^{RL} - 0.235z_{t-1}^{RS} - 0.120\Delta \pi_{t-1} \\
& (4.54) \quad (3.35) \quad (4.25) \quad (2.36) \\
& + 0.00428\Delta POIL_{t-1} + 0.634\Delta RTB10_{t-1} - 0.614\Delta RTB10_{t-2} \\
& (2.66) \quad (4.08) \quad (4.00)
\end{aligned} \tag{17}$$

$$\bar{R}^2 = 0.34$$

where *POIL* is the relative price of oil and  $\pi$  is the inflation rate ( $\pi = \Delta P$ ), and all growth rates are expressed in annualized terms.

Equation (13) suggests that output growth depends on the growth of potential GDP ( $\Delta Y^*$ ), the level of the output gap between actual and potential GDP ( $z_{t-1}^Y$ ), the gap between velocity and its long-run value ( $z_{t-1}^V$ ), the degree to which the yield curve slopes greater than average ( $z_{t-2}^{RS}$ ), and the first and third lags of the change in the 10-year interest rate (*RTB10*).

The yield curve slope term ( $z^{RS}$ ) accords with Laurent's theory. Equation (14) suggests that short-run velocity growth depends on its gap ( $z_{t-1}^V$ ), changes in short-term and long-term interest rates, the change in the output gap last period, and a time trend ( $DUMTIME$ ) beginning in 1991Q1 representing the sharp break in velocity that occurred at that time. Equation (15) implies that inflation changes in response to the gap between the price level and  $P^*$  ( $z_{t-1}^P$ ), the gap between long-term interest rates and their long-run equilibrium level ( $z_{t-1}^{RL}$ ), as well as lagged changes of the inflation rate, velocity, and the relative price of oil. The price gap term ( $z^P$ ) accords with Hallman, Porter, and Small (1991). According to equation (16), long-term interest rates depend in the short run on the deviation of both long-term interest rates and short-term interest rates from their long-run equilibrium values, and the contemporaneous change in the short-term interest rate. Finally, equation (17) is a monetary reaction function, which suggests that the central bank changes the short-term interest rate in response to the existence of an output gap ( $z^Y$ ), deviations of the long-term and short-term interest rates from their long-run equilibrium levels, and lagged changes in inflation, the relative price of oil, and long-term interest rates. The model is estimated using seemingly unrelated regression (SUR) techniques on the short-run equations. The estimation of the model leads to no surprises and is consistent with Taylor's original estimation.

## A Structural VAR Model

Our third model of the economy, based on Jordi Gali's (1992) study, is a structural vector autoregressive model intended to reflect a dynamic macroeconomic theory. Both demand shocks and supply shocks affect output in the short run, but only supply shocks have a permanent effect. The four variables of interest in the model are the log of real GDP ( $Y$ ), the interest rate on three-month Treasury bills ( $RTB03$ ), the CPI inflation rate ( $\pi$ ), and the log of real M1 money balances ( $RMI$ ). There are four structural shocks in the model, representing shocks to the main equations of a Keynesian model: an aggregate supply shock ( $e^{AS}$ ), a money supply shock ( $e^{MS}$ ), a money demand shock ( $e^{MD}$ ), and a spending shock ( $e^{IS}$ ).

The unrestricted VAR representation of the model is:

$$[I - B(L)]Z_t = v_t, \quad (18)$$

where  $Z$  is the (4 x 1) vector of variables  $[\Delta Y, \Delta RTB03, RTB03 - \pi, \Delta RMI]'$ ,  $I$  is a (4 x 4) identity matrix,  $B(L)$  is a (4 x 4) matrix polynomial in the lag operator with  $B(0) = 0$ , and  $v$  is a (4 x 1) vector of reduced-form disturbances for which  $E v_t v_t' = \Sigma_v$ . The reduced-form disturbances are related to the structural disturbances ( $e$ ) by the equation:

$$v_t = S e_t, \quad (19)$$

where  $e$  is the (4 x 1) vector  $[e^{AS}, e^{MS}, e^{MD}, e^{IS}]'$ ,  $E e_t e_t' = \Sigma_e$ , and  $S$  is the (4 x 4) matrix of contemporaneous structural coefficients.

Using equation (19) in equation (18) and multiplying through by  $S^{-1}$  gives the structural vector autoregressive (SVAR) relationship:

$$A^*(L)Z_t = e_t, \quad (20)$$

where  $A^*(L) \equiv S^{-1}[I - B(L)]$ .

To identify the model given by (20), we need to impose some restrictions on the matrices  $S$  and  $\Sigma_e$ . With  $N$ , the number of variables in the model, equal to four, the matrix  $\Sigma_e$  has  $N(N + 1)/2 = 10$  unknown parameters, and the matrix  $S$  has  $N^2 = 16$  unknown parameters. From equation (19), one restriction relates the variances of the structural and reduced-form disturbances:  $\Sigma_v = S\Sigma_e S'$ , which imposes 10 nonlinear restrictions on the system. Assuming the structural disturbances are contemporaneously uncorrelated, and imposing a normalization that the structural shocks have unit variance imposes  $N(N-1)/2 = 6$  and  $N = 4$  restrictions, respectively. Thus we need six more restrictions to identify the model.

The remaining six restrictions come from assumptions about the effects of structural disturbances on the variables of the model. Three restrictions come from assuming that only the aggregate supply shock has a permanent effect on any of the model's variables. Two additional restrictions come from assuming that real output doesn't respond contemporaneously to shocks to money supply or money demand. The final restriction comes from assuming that money supply doesn't respond contemporaneously to movements in inflation.

We follow Galí in using his method and in using beginning-of-quarter data to estimate the model. Estimation is difficult because the identifying restrictions are represented by a set



of nonlinear equations that must be solved simultaneously. Using repeated iterations of a simplex routine yields the following solution for the  $S$  matrix:

$$\hat{S} = \begin{bmatrix} -2.35 & 0.00 & 0.00 & -1.97 \\ 0.20 & 0.58 & 0.36 & -0.27 \\ -0.70 & 0.44 & 1.41 & 0.70 \\ -0.52 & -2.92 & 2.36 & -0.30 \end{bmatrix} \quad (21)$$

These results can be used to generate the contemporaneous relationships in the structural version of the model:<sup>5</sup>

$$\Delta Y_t = 2.48 + 3.06 \Delta RTB03 - 1.44(RTB03 - \pi) + 0.39 \Delta RM1 + e_t^{AS}/S^{11}, \quad (22)$$

$$\Delta RTB03 = -0.03 - 0.06 \Delta Y_t - 0.38(RTB03 - \pi) + 0.38 \Delta RM1 + e_t^{MS}/S^{22}, \quad (23)$$

$$RTB03 - \pi = -1.388 + 0.20 \Delta Y_t - 3.15 \Delta RTB03_t - 0.78 \Delta RM1 + e_t^{MD}/S^{33}, \quad (24)$$

$$\Delta RM1 = 0.07 - 1.54 \Delta Y_t - 7.80 \Delta RTB03 + 3.68(RTB03 - \pi) + e_t^{IS}/S^{44}, \quad (25)$$

where  $S^{ii}$  is the  $i$ th element on the main diagonal of the matrix  $S^{-1}$ .

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<sup>5</sup>Standard errors of the estimates are not presented here, as is also true in Gali's paper, because doing so would require far more computer power than we have available. In principle, such standard errors could be calculated using Monte Carlo methods, but the nature of the simultaneous nonlinear equations needed to estimate the model makes even these methods quite time- and computer memory-intensive.

Although Gali's intent in developing the model may have been to provide a dynamic version of the standard Keynesian *AS-AD*, *IS-LM* model, the estimated model looks quite different from typical textbook models. Nonetheless, its impulse response functions are quite similar to those one would expect of a Keynesian model. Our estimation has led to results quite close to those found by Gali.

### III. Simulation Results

This section reports the results of simulating our three models over the period 1963 to 1993 under the assumption that McCallum's rule had determined monetary policy. The simulation proceeds by drawing random shocks from a normal distribution and attaching them to each equation in a model for each date. The shocks are mean zero and their variance is the same as the variance of the residuals in the estimated model. The models are solved to yield simulated values of all the endogenous variables over the sample period. In Taylor's reduced-form model, we allow for covariance among the shocks. Rather than looking at just one simulation, which could have come from a particularly bad set of shocks, we simulate each model 500 times and examine the median and 95% confidence intervals for the simulations.

The Fed's desired rate of inflation ( $\Delta P^*$ ) is assumed to be 0% and, thus, the desired nominal GDP path ( $X^*$ ) is assumed to grow at a rate equal to the rate of growth of potential real GDP. As a result, we expect the rule's biggest impact to be a lower average simulated inflation rate than the actual average inflation rate. The rule should drive inflation to zero.<sup>6</sup>

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<sup>6</sup>Strictly speaking, this is true only in models in which monetary policy has no permanent effect on real output. Both the reduced-form and structural VAR models have such a

From the perspective of a policymaker, we are interested in two key questions. First, how susceptible are the models to dynamic instability? Second, when stable, how variable are nominal GDP and its components, prices and real GDP? The key to determining this is the size of the monetary response factor ( $\lambda$ ). Given that our goal is to see if the rule works well in a wide variety of models, we need the same monetary response factor to work in all different models. This would support McCallum's claims about the value of the rule.

### **Keynesian Model Results**

As estimated in equations (2) to (6), the model treats the monetary base as exogenous. For us to examine what would happen if McCallum's rule had been in effect, we introduce equation (1), McCallum's rule, into the model, making the monetary base endogenous. In implementing the rule, we first choose to use a monetary response factor ( $\lambda$ ) of 0.25. This value worked well in McCallum's research. This means that the Fed should increase the growth rate of the monetary base by 0.25 percent in a quarter for every 1 percent that nominal GDP falls below its target.

We begin each counterfactual simulation in 1963Q2 and carry it out to 1993Q2. The results for nominal GDP, real GDP, and the price level are shown in Figure 1. For each variable, the solid lines show the median value of the 500 simulations at each date and the upper and lower bounds defining the 95% range of the simulations. The long-dash line shows the target path for nominal GDP in the top figure--which, in most cases, cannot be

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property, while the Keynesian model does not.

distinguished from the median--and the level of potential real GDP in the middle figure. A short-dash line shows the historical value of each variable.

Several results are readily apparent from the figure. First, mirroring the findings of McCallum and Judd-Motley, nominal GDP is kept quite close to target (upper panel); furthermore, the 95% range of the simulations is below the historical path of nominal GDP. Second, the median path of real GDP is permanently below its potential level throughout the simulation (middle panel). This reflects, in part, the lack of a natural-rate mechanism in the model and initial conditions that call for an initial period of contractionary monetary policy to reduce inflation from its 1963 rate of roughly 1.5% to its desired rate of 0%. Finally, inflation is lower in the simulations than it was historically, so the rule is effective in controlling inflation (lower panel).

To get a different perspective on the results, Table 1 presents some useful summary statistics. It shows, for the simulations with McCallum's rule (the column labeled "Level Target"), the average values of nominal GDP growth, real GDP growth, and inflation, plus the standard deviations of the quarter-over-quarter log first-differences of nominal GDP, real GDP, and the price level. To get a summary empirical estimate of the degree to which the economy hits its target, we measure the root-mean-squared deviation (RMSD) of nominal GDP from its target; to get a summary measure of the economy's divergence from its full-employment level, we calculate the RMSD of real GDP from its potential level. For each measure, we show the median value, as well as the lower bound (Low) and upper bound (High) representing the range into which 95% of the values fall.

A natural question to ask about McCallum's rule is: How does McCallum's rule compare to other rules that might be worth considering? In Table 1, we compare it to a natural yardstick: a rule that sets the monetary base growth rate at a constant level equal to the growth rate of potential GDP. This is a rule without feedback--it does not allow the monetary authority to respond to economic conditions, as does McCallum's rule. The constant-base-growth simulations, reported in Table 1, highlight the crucial role of feedback in McCallum's rule: the 95% ranges for both nominal GDP growth and inflation are noticeably wider than was the case with McCallum's rule. Not surprisingly, the RMSD of nominal GDP is much higher. Comparing standard deviations across rules, the constant-base-growth simulation indicates that nominal and real GDP growth are a bit less variable on a quarter-over-quarter basis. Taken together, our Keynesian-model simulations suggest that McCallum's rule affords a high degree of control over the long-run growth of nominal variables (prices, nominal GDP) but that this control may come at the expense of increased quarter-over-quarter variability in real GDP.<sup>7,8</sup>

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<sup>7</sup>Judd-Motley (1991) also find an increase in short-run real GDP variability. Note that, following McCallum, our findings on the behavior of real GDP are likely to be particularly susceptible to the Lucas critique. We thank Bennett McCallum for suggesting an alternative to the Keynesian model that allows inflation in (3) to depend on contemporaneous, rather than on lagged, output. The results obtained by reestimating (3) and conducting a new set of stochastic simulations indicate that while long-run growth in real output and prices is about the same as in the original model, the 95% intervals are much tighter. In keeping with our desire to maintain the models' specification as close as possible to its original form, we focus attention on our initial specification of (3), as reported.

<sup>8</sup>Our Keynesian model simulations are conducted by first setting to zero the exogenous variables in the model. Thus, following model estimation we set to zero all values of  $\Delta PIM$  and  $\Delta E$  both in the constant-base-growth simulation and in the simulations with McCallum's rule. We do this primarily to eliminate the implausibly large effect that oil shocks, operating

A final important feature of McCallum's rule is that it does not generate economic instability in this model. Research on rules for monetary policy often finds that following rules leads to unstable economic performance. The instability could come from one of two places: it could be inherent in the model, or it could be induced by the policy rule. To demonstrate that this model has no such problem, we examine impulse responses to see how the economy responds to a shock. These are plotted in Figure 2, which traces the response over time of the Keynesian model's endogenous variables to two different shocks: a shock to the *IS* equation (2) and a shock to the *AS* equation (3). We do this for two different cases: one in which we treat the monetary base as exogenous (which corresponds to our constant-base-growth simulation), and another in which we impose McCallum's rule. If the model itself is causing instability, both impulse response functions should show accelerating fluctuations over time. But if McCallum's rule is inducing fluctuations, then the model treating the base as exogenous should not display accelerating fluctuations.

As Figure 2 indicates, when the monetary base is taken to be exogenous (solid line), the impulse responses eventually settle down—an indication that the model is stable. The impulse responses also settle down when McCallum's rule is in place (dashed line), which suggests that McCallum's rule does not induce instability in the model.

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through PIM, have on real output in the model—due to the absence of a natural rate mechanism. Simulations with McCallum's rule conducted by allowing  $\Delta PIM$  and  $\Delta E$  to take their historical values indicate that the main effect is to change the split of average nominal GDP growth into real growth and inflation, leaving average simulated nominal GDP growth at the same rate as in the simulations that set the exogenous variables to zero. Thus, McCallum's rule prevents the exogenous variables from affecting nominal GDP but allows an effect on real GDP and the price level.

Overall, then, McCallum's rule with  $\lambda = 0.25$  works well in keeping inflation low and maintaining economic stability in the Keynesian model.

### Reduced-Form Model Results

In simulating the reduced-form model, we must make one modification to the model. Since we plan to use McCallum's rule in the model instead of the federal funds rate reaction function in the original model, we need to add a relationship between the federal funds rate, the monetary base, and the M2 measure of the money supply. We do this with a money multiplier specification:

$$\begin{aligned} \Delta \hat{MM2}_t = & 0.583 \Delta MM2_{t-1} + 0.252 \Delta MM2_{t-2} - 0.578 \Delta RFF_t, \\ & (7.10) \qquad (2.98) \qquad (3.06) \end{aligned} \tag{26}$$

$$\bar{R}^2 = 0.58$$

where  $MM2$  is the M2 money multiplier,  $RFF$  is the federal funds rate, and all variables are expressed in annualized terms. Equation (26) is the most parsimonious of several alternative specifications that we estimated.

The 500 simulations of this model with  $\lambda = 0.25$  show that McCallum's rule works quite well in stabilizing nominal and real GDP as well as the price level (Figure 3).<sup>9</sup> The median simulation path for real GDP is quite close to its potential level. The price level is also stabilized quite well. Inflation is close to zero as a result of using McCallum's rule.

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<sup>9</sup>For simulation purposes, we set to zero the dummy variables in equations (10) and (14) and the exogenous variable  $\Delta POIL$  in equation (15).

Table 2 illustrates these results more clearly. A comparison of RMSDs obtained by simulating the model under McCallum's rule and under a constant-base-growth rule suggests that McCallum's rule is on average better able to hit the nominal GDP target and that real GDP is closer, on average, to its potential level. As was the case in the Keynesian model, holding nominal GDP closer to target comes at the cost of a higher standard deviation of quarter-over-quarter changes in both real and nominal GDP. McCallum's rule keeps the average rate of inflation close to its desired rate of zero, with a much tighter 95% range and with a lower standard deviation than does the constant-base-growth rule.

The impulse responses (Figure 4) in this model show clearly how the rule may induce short-run fluctuations in the economy in response to an output shock in equation (13) or to an inflation shock in equation (15). When the monetary base is exogenous (solid line), the response of variables over time to the shock displays a smooth return to equilibrium in the case of an output shock, or damped oscillations in the case of an inflation shock. In contrast, with McCallum's rule and  $\lambda = 0.25$  (dashed line), the shocks lead to sharper short-run movements in real and nominal GDP, interest rates, and money growth.

### **Structural VAR Model Results**

To incorporate McCallum's rule into the structural VAR model, we again add a money-multiplier equation. This provides a relationship between the M1 measure of the money supply, which is the monetary variable in the structural VAR model, and the monetary base, which enters McCallum's rule. As in the reduced-form model, we allow the money



multiplier to depend on interest rates--in this case the three-month T-bill rate. The equation for the money multiplier is:

$$\begin{aligned} \Delta \hat{MMI}_t = & 0.022 \Delta MMI_{t-1} + 0.172 \Delta MMI_{t-2} + 0.187 \Delta MMI_{t-3} \\ & (0.25) \qquad (1.97) \qquad (2.13) \\ & - 0.754 \Delta RTB03_{t-1} - 0.479 \Delta RTB03_{t-2} - 0.594 \Delta RTB03_{t-3} \\ & (2.64) \qquad (1.65) \qquad (2.14) \end{aligned} \tag{27}$$

$$\bar{R}^2 = 0.11$$

Simulations of the model with  $\lambda = 0.25$  (Figure 5) are similar to those from the Keynesian model. As in the Keynesian model, the 95 percent ranges for real GDP and the price level widen slightly over time. This widening of the ranges occurs for nominal GDP as well, unlike the Keynesian model.

In the structural VAR, unlike in the other models, McCallum's rule introduces instability, as demonstrated by the impulse responses (Figure 6). Shocks to the IS relationship or the AS relationship induce increasing oscillations in real GDP, prices, nominal GDP, interest rates, and money growth (dashed line). This is a serious problem for McCallum's rule, because it suggests that the rule isn't robust across reasonable models of the economy. Importantly, the model is not inherently unstable, as indicated by the constant-base-growth impulse responses (solid line).

#### IV. Stability and Modifications of McCallum's Rule

In all three models, McCallum's rule is useful in reducing inflation, on average. The average level of real output is about at its potential level, while the price level is much lower

in the simulations than it was historically. However, in the structural VAR model, McCallum's rule introduces instability.

Is there a way to modify the rule to alleviate the instability problem? There are two possibilities: (1) we could change the monetary response factor ( $\lambda$ ); (2) we could modify the form of the rule. McCallum tried both variations in his earlier research and seems to be leaning in favor of the latter variation, which in practice has meant targeting the growth rate of nominal GDP rather than the level. In a 1993 paper, McCallum suggests a combination target involving both the level and growth rate of nominal GDP.

How do such variations work in our set of models? First, we examine variations in the monetary response factor ( $\lambda$ ). Then, we look at what happens when we target nominal GDP growth instead of the level of nominal GDP.

We begin by conducting some additional simulations with different values of the monetary response factor ( $\lambda$ ). Doing a crude search across values of  $\lambda$ , we find that the structural VAR model is dynamically stable under McCallum's rule with a  $\lambda$  between 0.40 and 0.80. Such a large value of  $\lambda$  implies a large policy response to any deviation of nominal GDP from its target, so that nominal GDP hits its target very closely (Figure 7). Both real GDP and the price level are stabilized quite well, and the range of the simulations is quite narrow. The impulse responses in Figure 8, using  $\lambda = 0.80$ , indicate that the endogenous variables continue to exhibit relatively higher short-run variability in response to shocks compared with the constant-base-growth rule and that the model with McCallum's rule is dynamically stable.

Thus, our results indicate that we need a higher value for the monetary response factor than McCallum's base value of  $\lambda = 0.25$  to make the structural VAR model stable. Raising  $\lambda$  creates no problems in the Keynesian model. However, as we increase  $\lambda$ , to alleviate the problem of instability in the structural VAR model, we find instability in the reduced-form model. In fact, even a  $\lambda$  as low as 0.35 introduces instability into the reduced-form model, as illustrated by the impulse responses in Figure 9.

Thus, our investigation of modifying the size of the monetary response factor has left us with the result that there is no value of  $\lambda$  for which all three models are stable. For that reason, we now examine McCallum's (1993) other suggested strategy: a rule that targets the growth rate, rather than the level, of nominal GDP. This represents a modification of equation (1) to the following:

$$\Delta B_t = (\Delta P_t^* + \Delta Y_t^*) - \Delta \tilde{V}B_t + \lambda(\Delta X_{t-1}^* - \Delta X_{t-1}). \quad (28)$$

McCallum has found that this variation of the rule seems to work well. It has the potential, however, of allowing drift in the level of nominal GDP.

In all three of our models, this variation of McCallum's rule works well with the monetary response factor set at  $\lambda = 0.25$ . All the models are stable, as shown by the impulse responses in Figure 10 (Keynesian model), Figure 11 (reduced-form model), and Figure 12 (structural VAR model). In Tables 1, 2, and 3, summary statistics for the stochastic simulations are shown in the columns labeled "Growth Target."

In the Keynesian model, Table 1 shows that the switch to the growth target from the level target leaves mean growth rates about the same, reduces the standard deviations of real

and nominal GDP growth but raises the standard deviation of inflation, and raises the RMSD of both nominal and real GDP. Since we still measure the target as the level of nominal GDP and real GDP, it isn't surprising that the RMSDs rise when we modify the rule to feed back on the growth rate of nominal GDP rather than its level.

In the reduced-form model, Table 2 shows results similar to that of the Keynesian model, with the same qualitative differences between the results with the level target and the growth target.

In the structural VAR model, Table 3 shows that the growth-rate rule is better than the level rule in all aspects: the mean growth rates have a narrower range, the standard deviations are much lower, and the RMSDs are also lower. The improved all-around performance is attributable to the fact that following the growth-rate rule eliminates the instability problem found with the level rule.

## **V. Summary and Conclusions**

We began our investigation concerned about the robustness of McCallum's rule for the growth in the monetary base in three previously untested models. We found some problems of dynamic instability with McCallum's original formulation of the rule, which targets the level of nominal GDP. In addition, our stochastic simulations indicated a tendency toward higher short-run variability in nominal and real GDP compared with the variability produced in a baseline constant-base-growth simulation. When modified to feed back on the growth rate of nominal GDP instead of the level, as suggested in McCallum (1993), the rule appears to work well--both in terms of dynamic stability and in our short-run variability measure--across our

set of very different models. Our analysis of the models' impulse responses was shown to be useful in demonstrating when dynamic instability is an issue and in describing how McCallum's rule affects the models' responses to several types of shocks; we find that all the models are stable with McCallum's rule in growth-rate form.

Just as with all other policy changes, the Lucas critique is an important limitation to our simulation results. We don't have a good idea of how people's behavior would change if the Fed were to implement McCallum's rule. As macroeconomists develop new theories of behavior, we may be better able to simulate the effects of using McCallum's rule.

McCallum's rule is a potentially useful rule for setting monetary policy. Had the rule been followed over the past 30 years, inflation would have been much lower than it actually was. Given the concern over inflation that arose in the 1970s and early 1980s, McCallum's rule could serve as a useful device to guide monetary policy today.

Table 1

Summary Statistics - Keynesian Model,  $\lambda = 0.25$   
(Annualized percentage points)

	McCallum's Rule Level Target		Constant Base Growth Rule		McCallum's Rule Growth Target	
	Median	High	Median	High	Median	High
Mean growth rate of:						
Nominal GDP	2.77	2.40	3.54	1.20	2.73	2.20
Real GDP	2.62	1.20	2.99	1.75	2.55	1.02
Price level	0.15	-1.37	0.47	-1.75	0.15	-1.32
		1.47		2.65		1.84
Standard deviation of growth rate of:						
Nominal GDP	4.70	3.83	4.32	3.62	4.31	3.62
Real GDP	4.64	3.84	4.03	3.47	4.18	3.52
Price level	1.94	1.45	2.02	1.46	1.97	1.48
		2.63		2.93		2.80
Root-mean-squared deviations from target (RMSD):						
Nominal GDP	4.77	2.92	19.33	5.35	6.58	3.66
Real GDP	13.05	5.60	11.04	4.21	13.44	5.02
		33.85		27.46		37.94

Table 2  
 Summary Statistics - Reduced-Form Model,  $\lambda = 0.25$   
 (Annualized percentage points)

	McCallum's Rule Level Target			Constant Base Growth Rule			McCallum's Rule Growth Target		
	Median	Low	High	Median	Low	High	Median	Low	High
Mean growth rate of:									
Nominal GDP	2.73	2.38	3.09	3.25	0.60	5.42	2.59	2.16	3.00
Real GDP	2.85	2.27	3.41	2.85	1.79	3.80	2.85	2.23	3.50
Price level	-0.13	-0.53	0.32	0.33	-2.28	2.74	-0.26	-0.82	0.25
Standard deviation of growth rate of:									
Nominal GDP	8.11	6.19	10.48	6.27	5.13	8.12	6.23	5.27	7.70
Real GDP	8.12	6.17	10.45	6.19	4.82	8.60	6.32	5.19	8.19
Price level	1.86	1.43	2.30	3.38	1.97	5.45	2.25	1.64	3.15
Root-mean-squared deviations from target (RMSD):									
Nominal GDP	5.12	3.60	7.11	22.45	8.55	55.19	7.33	4.52	10.65
Real GDP	8.07	5.28	11.78	12.40	6.31	20.89	9.34	5.79	13.75

Table 3  
 Summary Statistics - Structural VAR Model,  $\lambda=0.25$   
 (Annualized percentage points)

	McCallum's Rule Level Target			Constant Base Growth Rule*			McCallum's Rule Growth Target		
	Median	Low	High	Median	Low	High	Median	Low	High
Mean growth rate of:									
Nominal GDP	2.73	1.72	3.85	2.92	1.14	4.46	2.72	2.13	3.29
Real GDP	2.82	1.79	3.92	2.79	2.02	3.53	2.85	2.04	3.63
Price level	-0.07	-1.57	1.10	0.14	-1.95	2.01	-0.14	-1.20	0.84
Standard deviation of growth rate of:									
Nominal GDP	7.65	4.45	15.06	4.60	3.78	6.17	4.88	3.85	6.97
Real GDP	5.85	3.94	10.40	3.68	3.22	4.19	3.98	3.35	4.86
Price level	6.53	3.05	13.99	3.60	2.43	5.79	4.06	2.34	7.25
Root-mean-squared deviations from target (RMSD):									
Nominal GDP	8.88	3.37	18.87	15.89	5.83	36.33	6.62	3.41	12.32
Real GDP	10.95	5.60	22.70	8.78	3.41	21.13	9.04	4.08	19.95

\* The constant-base-growth rule in this model includes a correction term to account for nonzero M1 velocity growth over the sample period, where M1 is the monetary aggregate appearing in the model. The rule takes the form  $\Delta B = \Delta Y^* - 1.58\%$ , where  $\Delta B$  and  $\Delta Y^*$  are the rates of growth in the monetary base and potential real GDP (in annualized percentage points), and 1.58 is average M1 velocity growth, in annualized percentage points, over the period 1959 to 1993. We make this correction in anticipation that it will produce an average simulated inflation rate close to zero, as in the other models, in our constant-base-growth simulation. The main effect of making this correction, compared with a simulation that does not include the correction, is to reduce average simulated inflation and nominal GDP growth by 1.46 and 1.55 percentage points. The RMSD for nominal GDP falls by 16 percentage points. Average simulated real GDP growth is roughly unchanged, as are the standard deviations.



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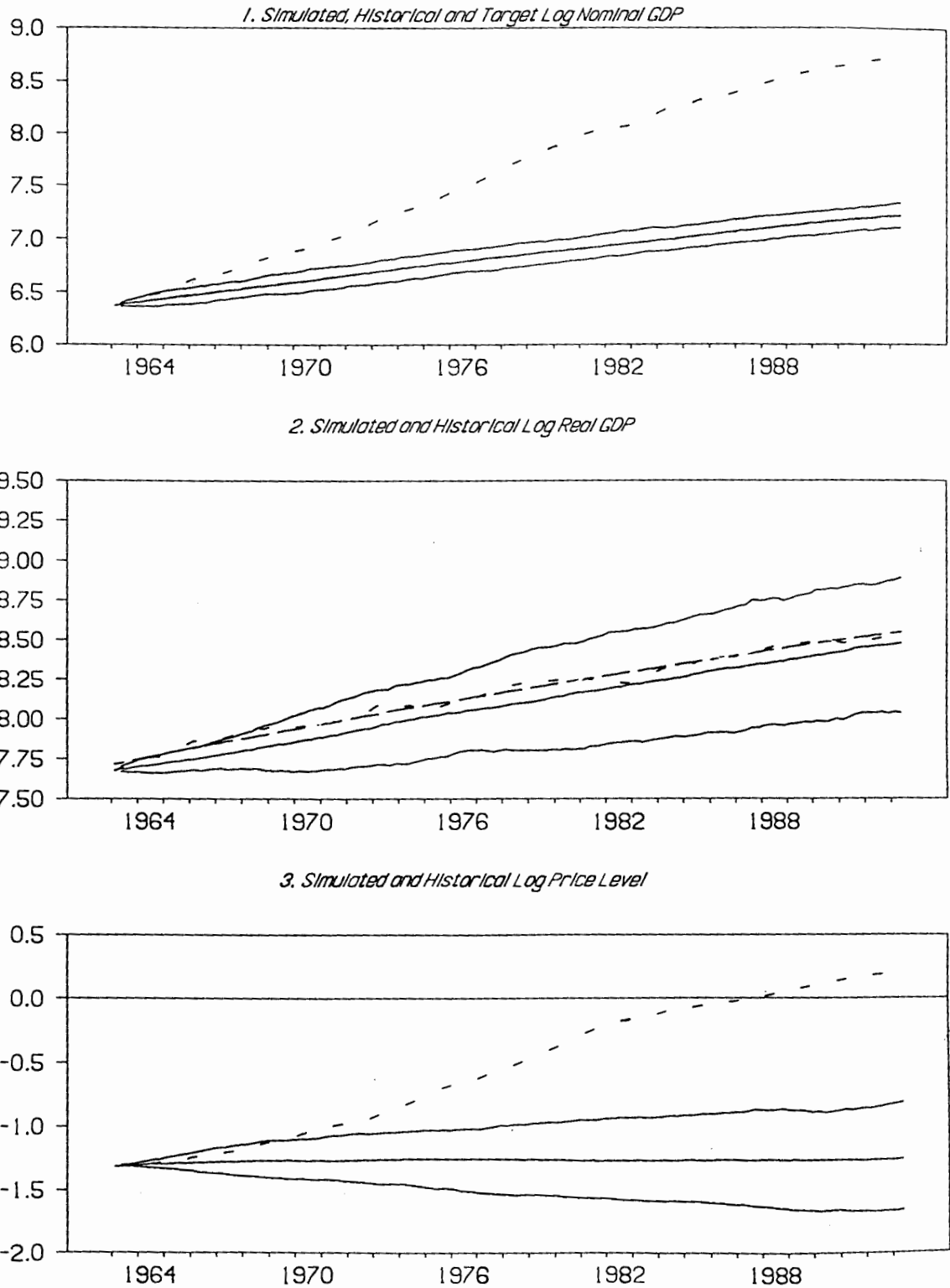
Taylor, John B. "Aggregate Dynamics and Staggered Contracts," *Journal of Political Economy* 88 (February 1980), pp. 1-24.

**Figure 1. Keynesian Model Simulations,  $\lambda = 0.25$ , Level Target**

(Solid Lines: 95% range and median

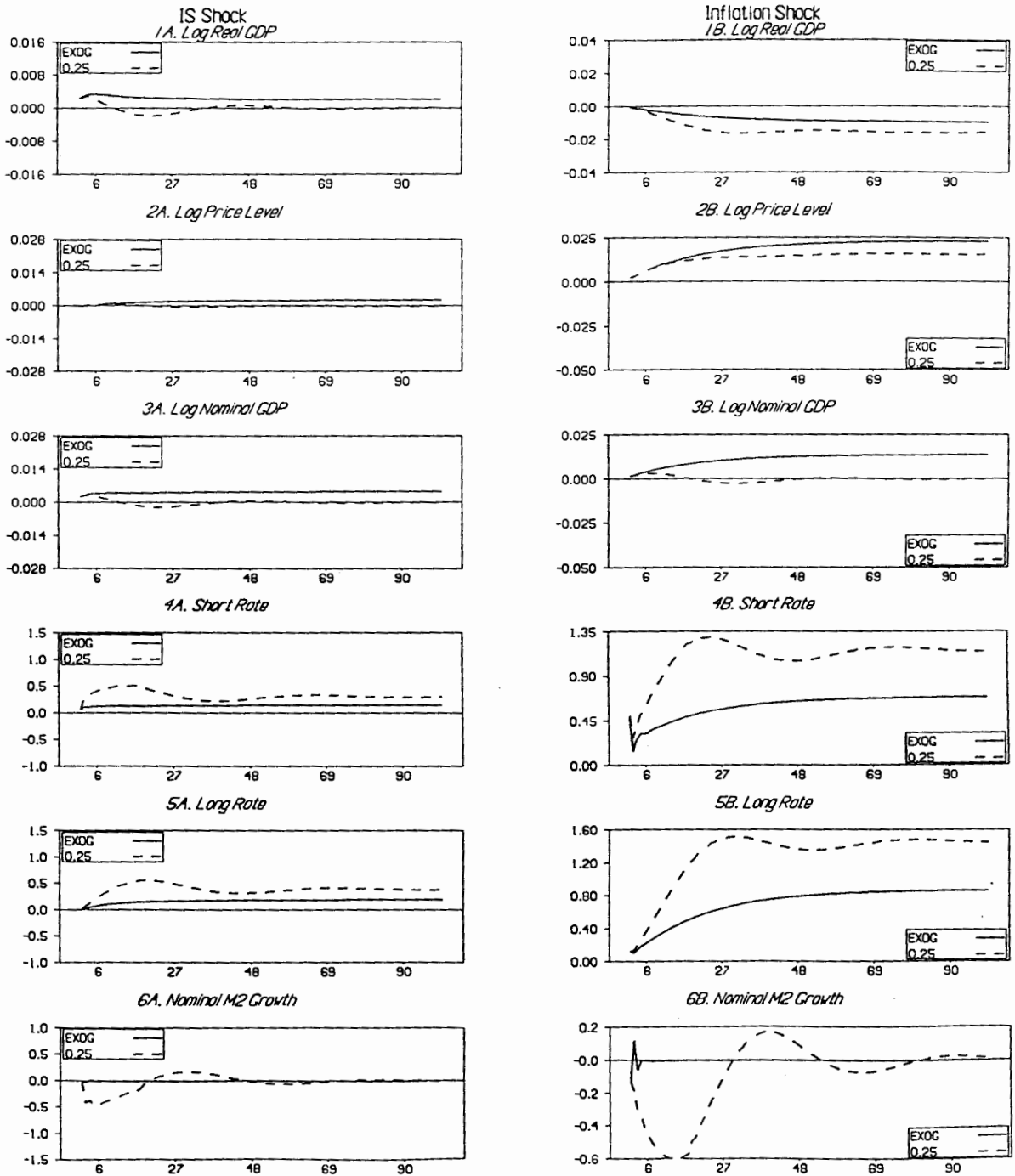
Short Dash Lines: historical values

Long Dash Lines: target values)



### Figure 2. Keynesian Model Impulse Responses

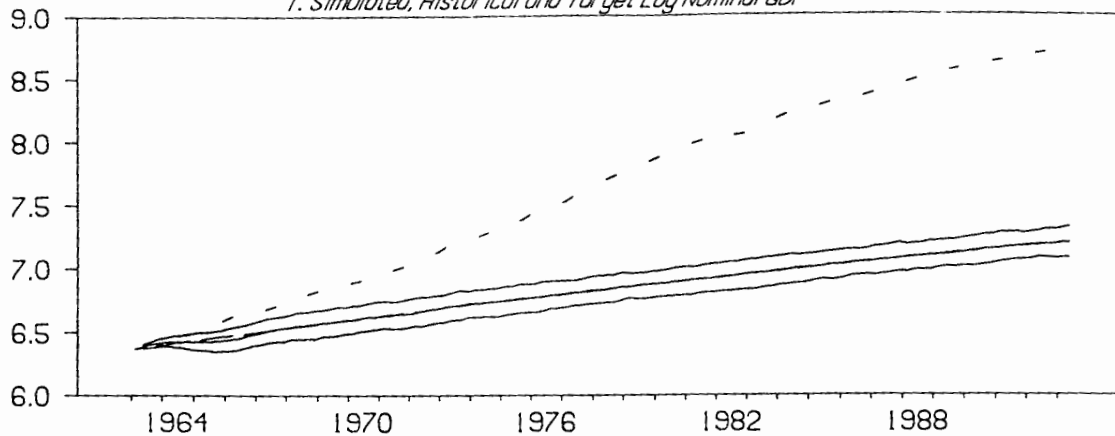
(Solid Lines: Exogenous Monetary Base Growth  
 Dash Lines: McCallum's Rule,  $\lambda=0.25$ , Level Target)



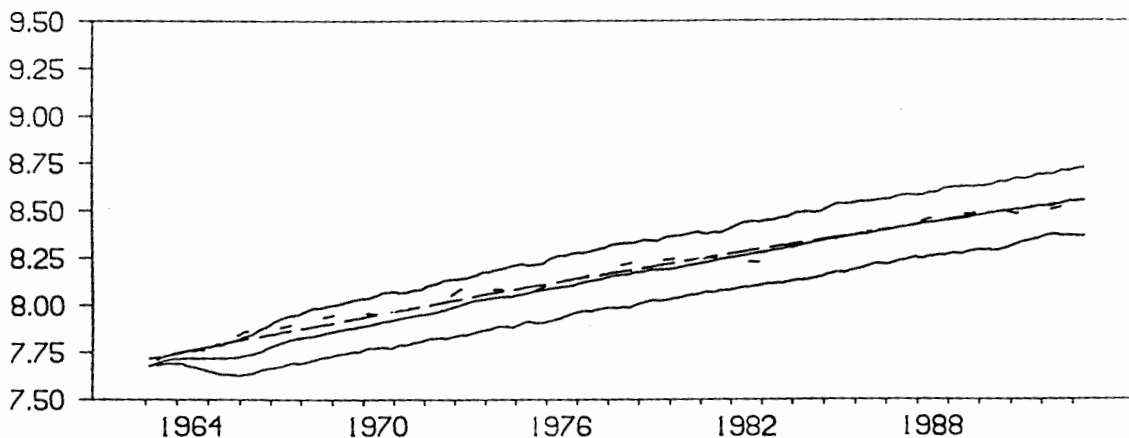
**Figure 3. Reduced-Form Model Simulations,  $\lambda=0.25$ , Level Target**

(Solid Lines: 95% range and median  
Short Dash Lines: historical values  
Long Dash Lines: target values)

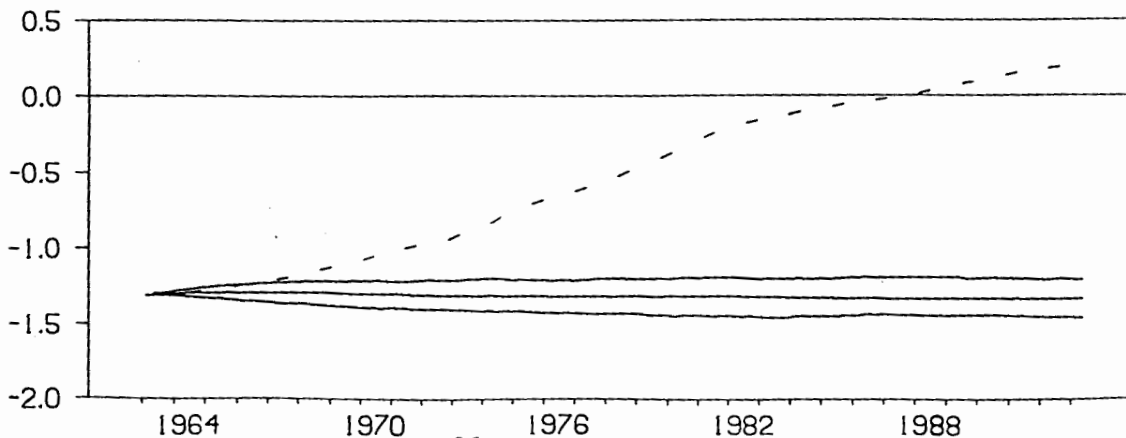
*1. Simulated, Historical and Target Log Nominal GDP*



*2. Simulated and Historical Log Real GDP*



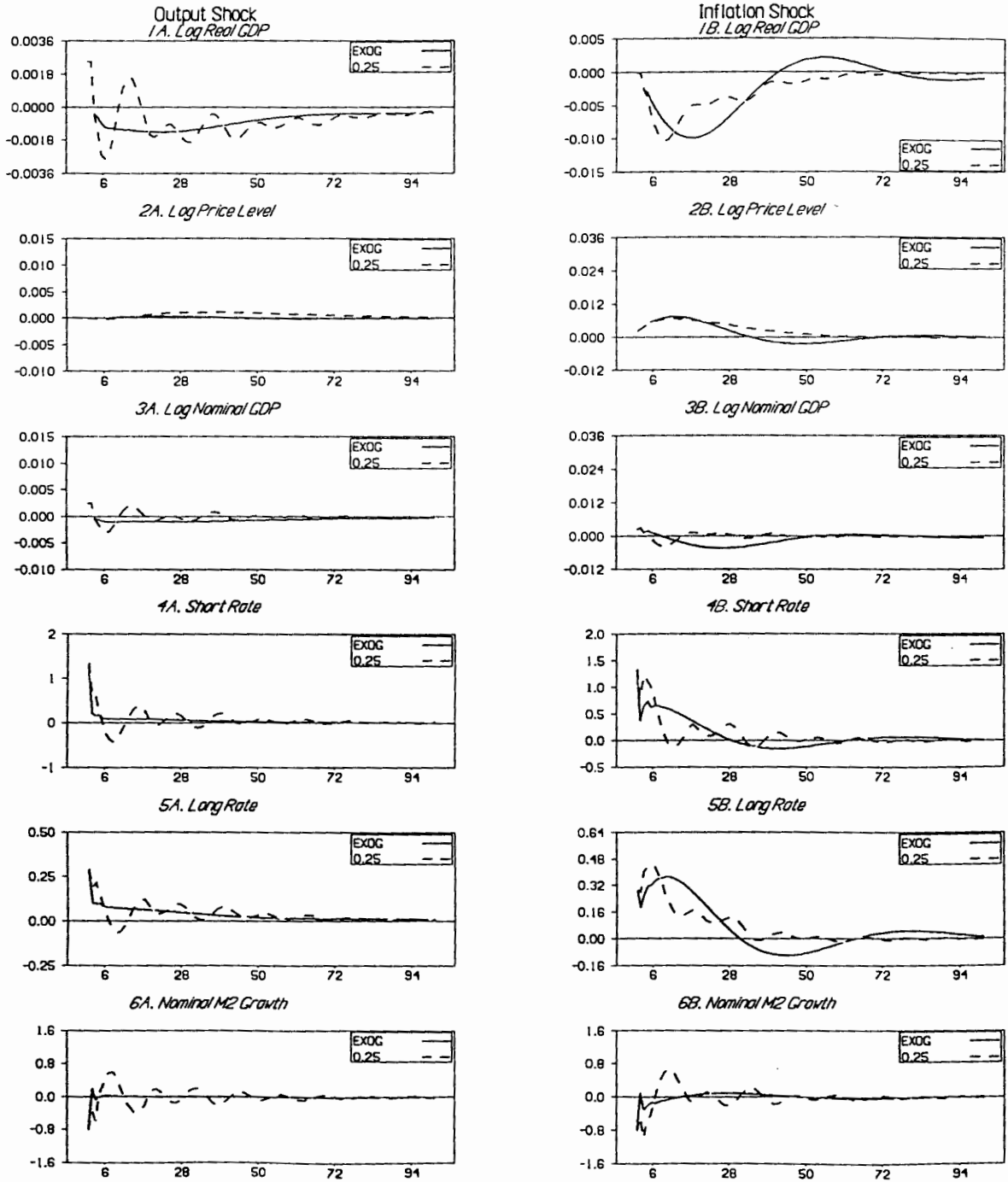
*3. Simulated and Historical Log Price Level*



### Figure 4. Reduced-Form Model Impulse Responses

(Solid Lines: Exogenous Monetary Base Growth)

(Dash Lines: McCallum's Rule,  $\lambda=0.25$ , Level Target)



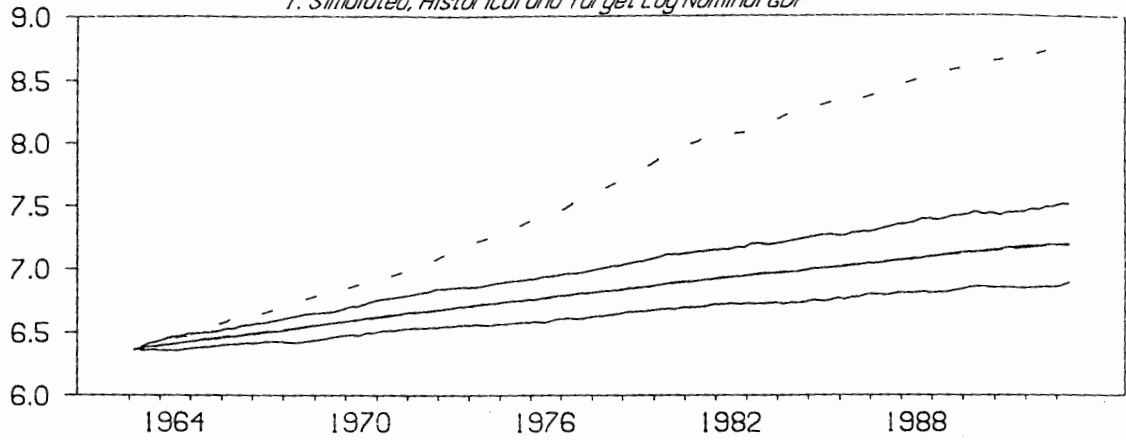
**Figure 5. Structural VAR Model Simulations,  $\lambda = 0.25$ , Level Target**

(Solid Lines: 95% range and median)

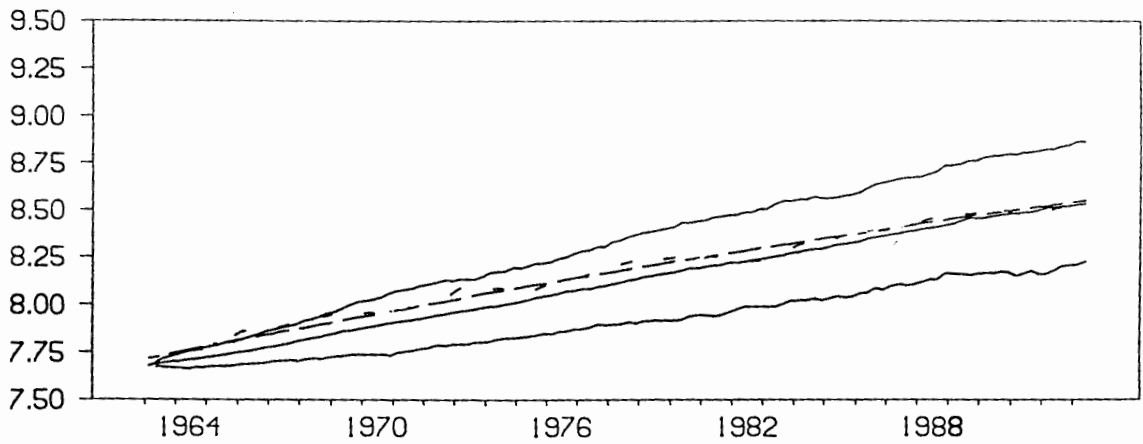
Short Dash Lines: historical values

Long Dash Lines: target values)

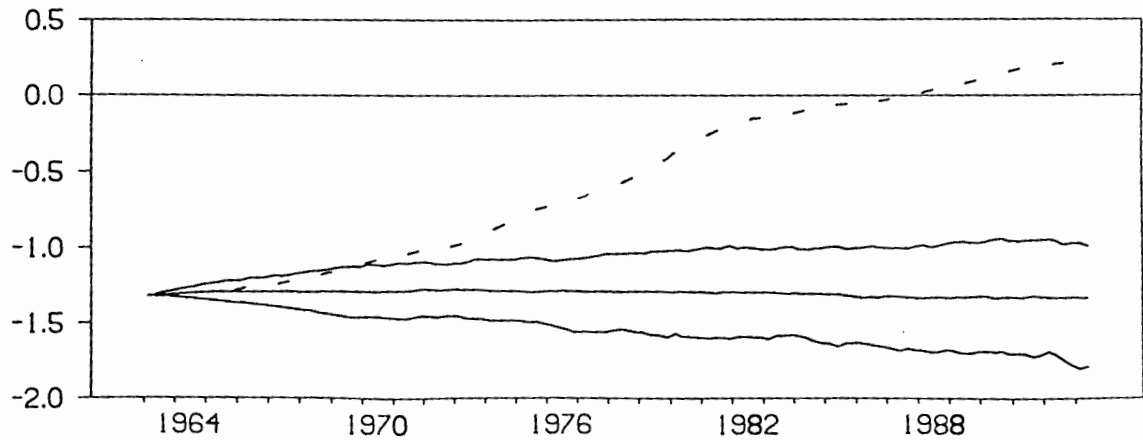
*1. Simulated, Historical and Target Log Nominal GDP*



*2. Simulated and Historical Log Real GDP*



*3. Simulated and Historical Log Price Level*

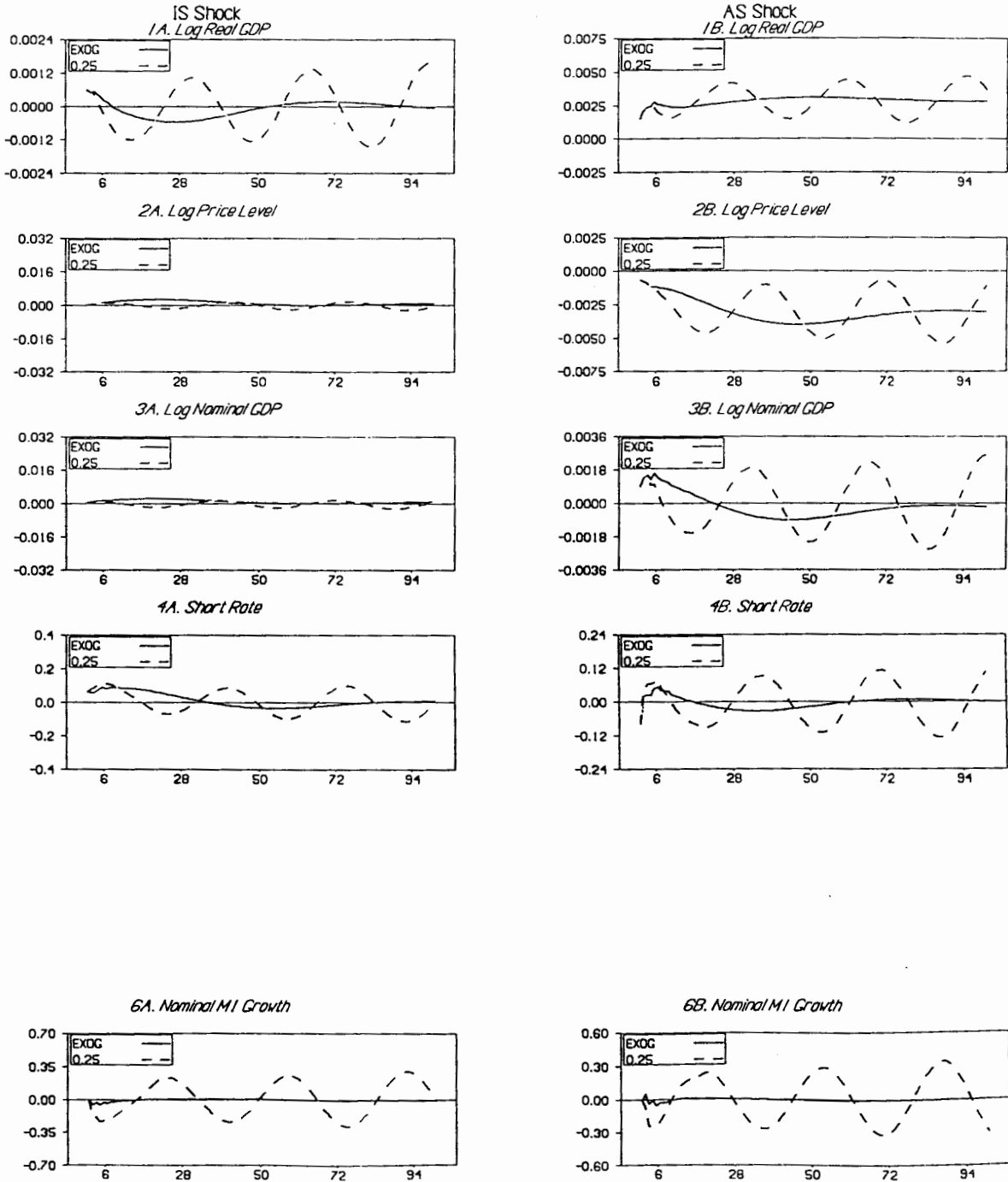




### Figure 6. Structural VAR Model Impulse Responses

(Solid Lines: Exogenous Monetary Base Growth)

(Dash Lines: McCallum's Rule,  $\lambda=0.25$ , Level Target)



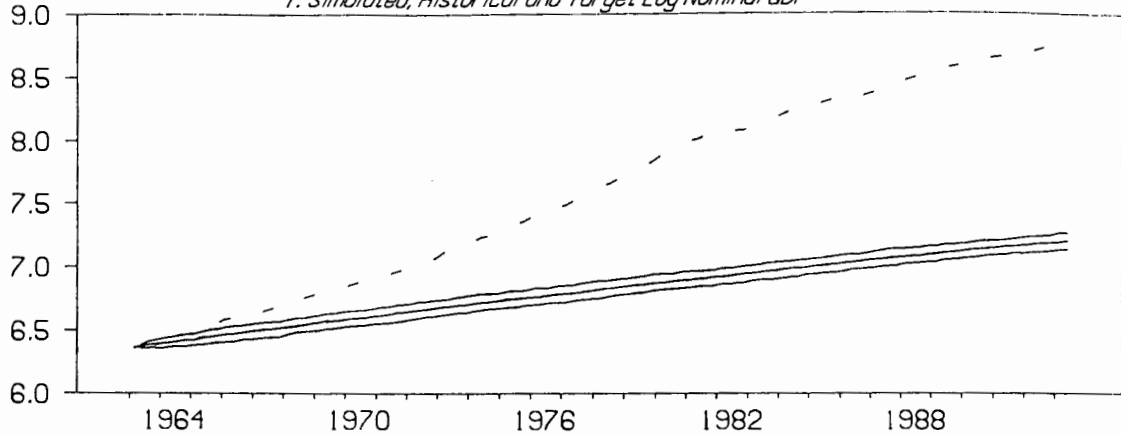
**Figure 7. Structural VAR Model Simulations,  $\lambda = 0.80$ , Level Target**

(Solid Lines: 95% range and median)

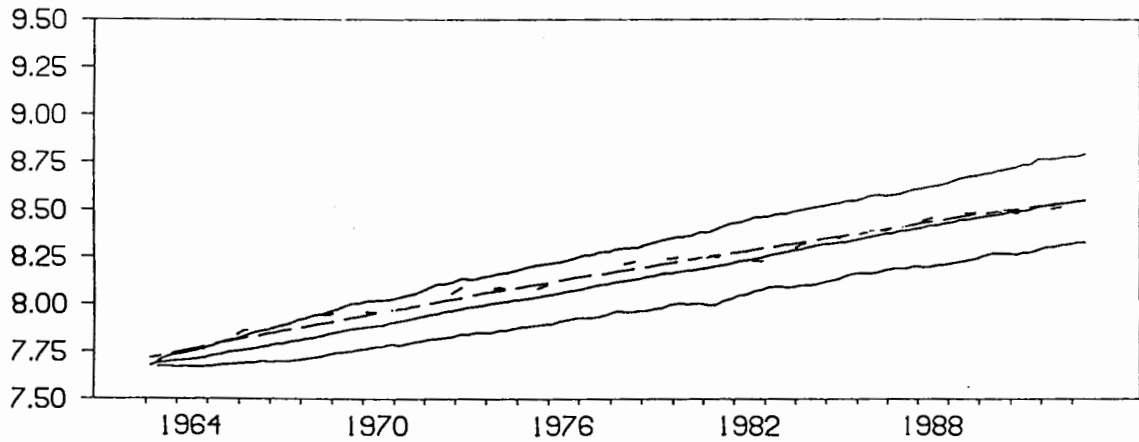
Short Dash Lines: historical values

Long Dash Lines: target values)

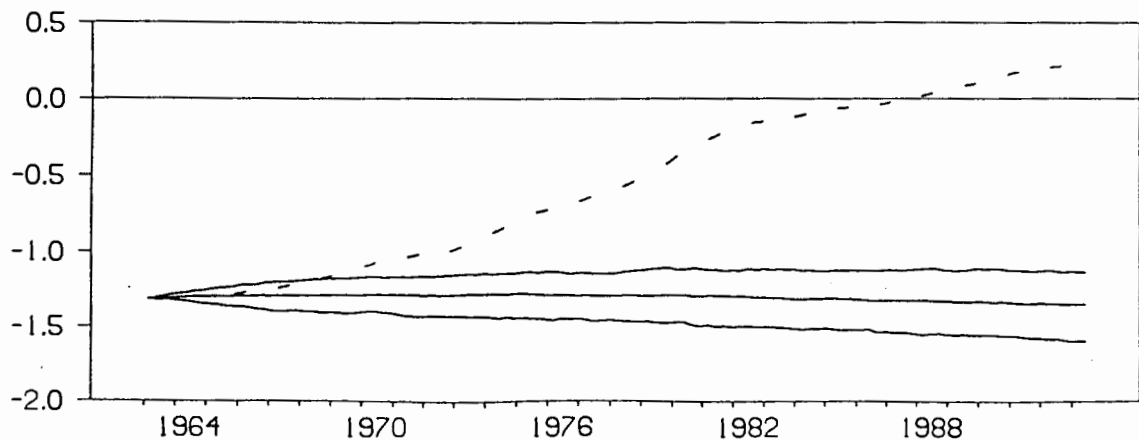
*1. Simulated, Historical and Target Log Nominal GDP*



*2. Simulated and Historical Log Real GDP*

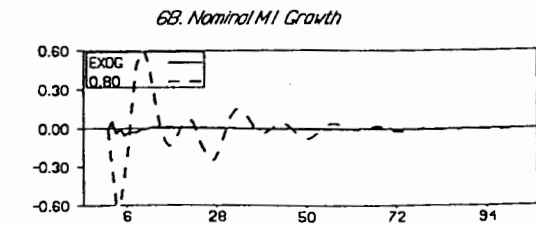
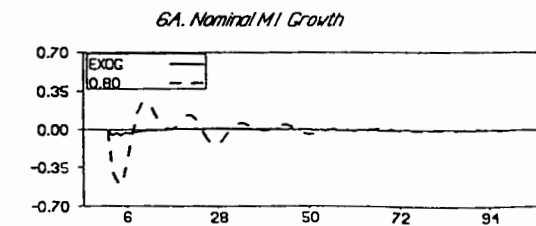
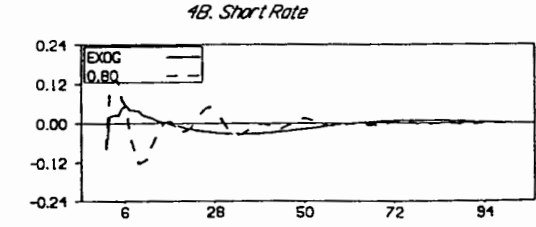
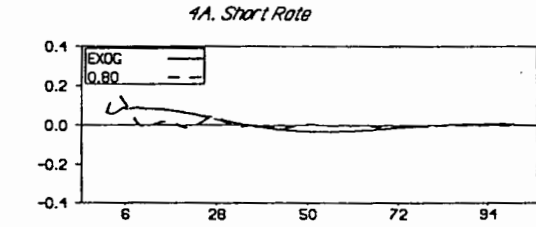
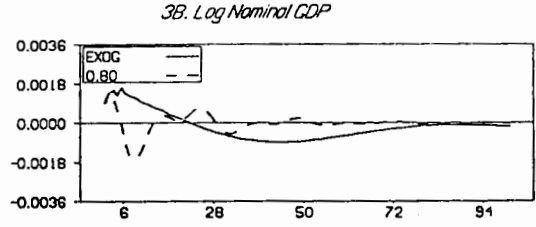
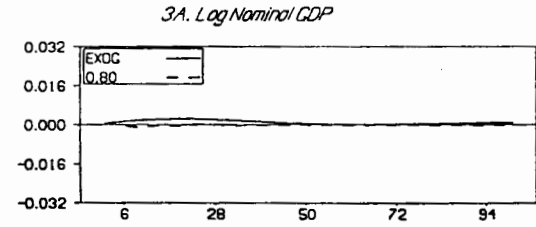
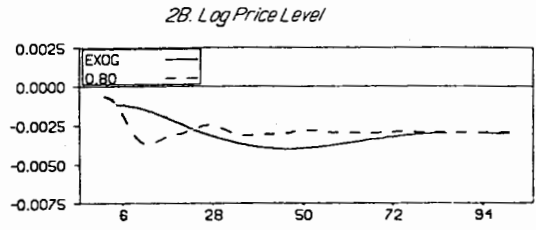
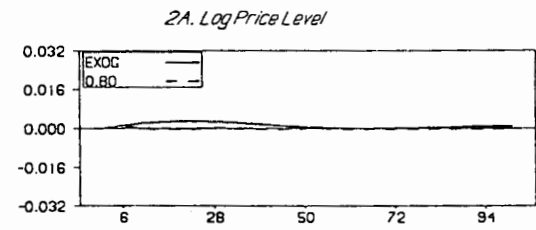
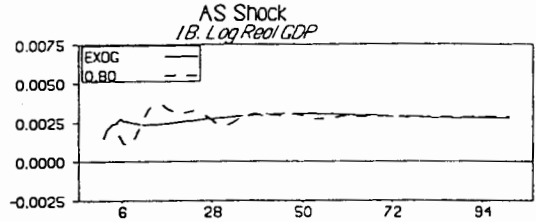
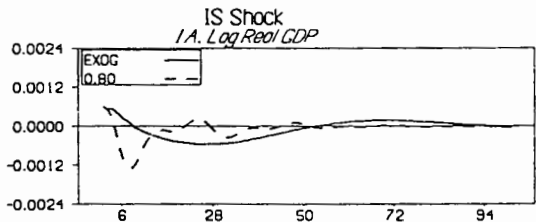


*3. Simulated and Historical Log Price Level*



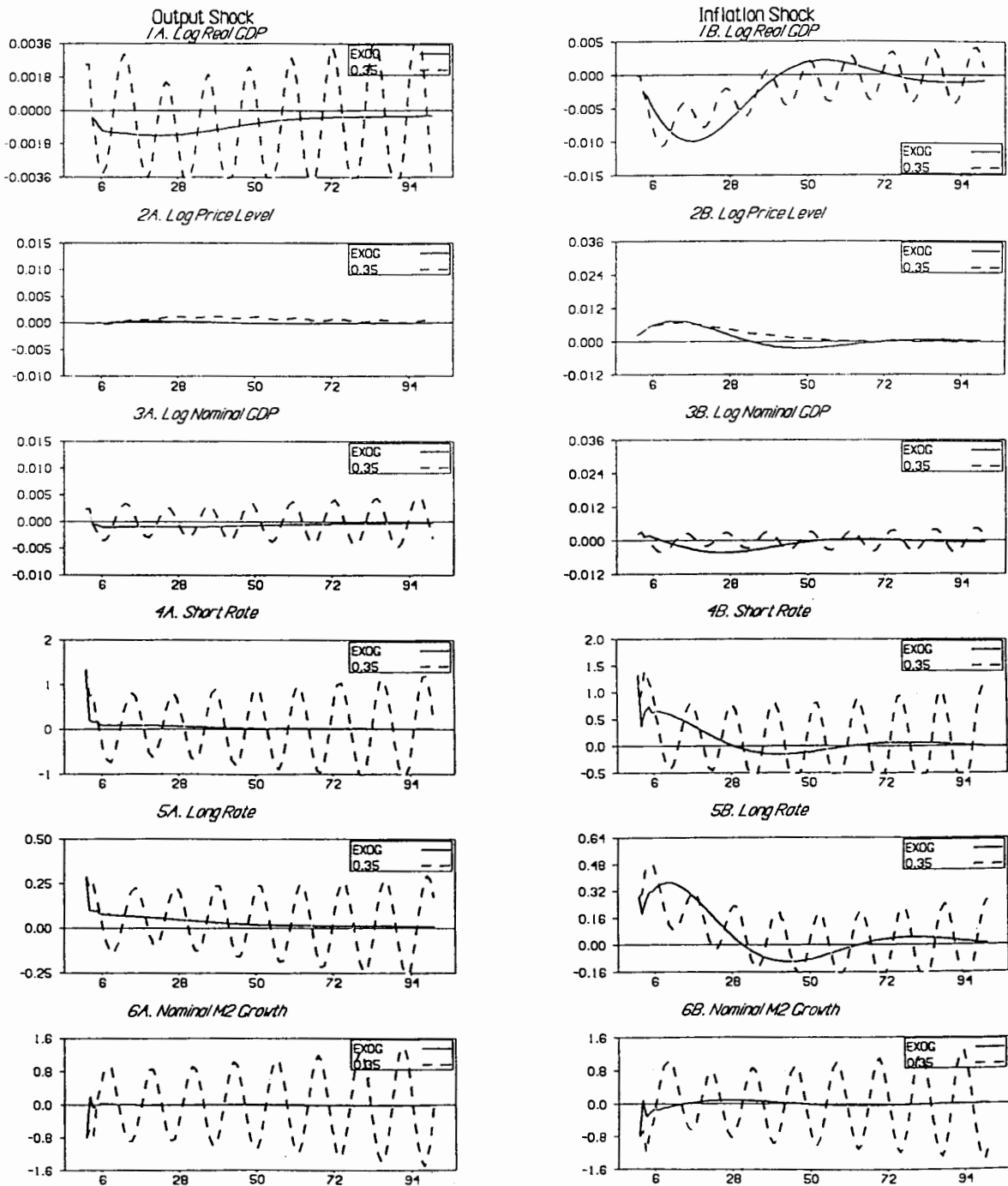
### Figure 8. Structural VAR Model Impulse Responses

(Solid Lines: Exogenous Monetary Base Growth  
 Dash Lines: McCallum's Rule,  $\lambda=0.80$ , Level Target)

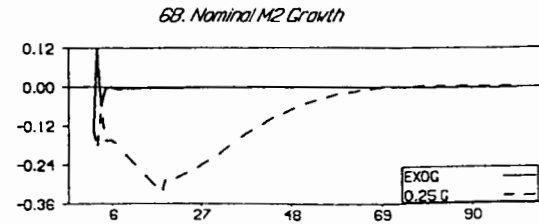
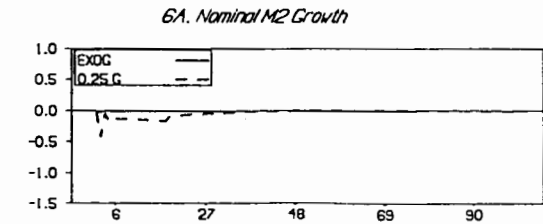
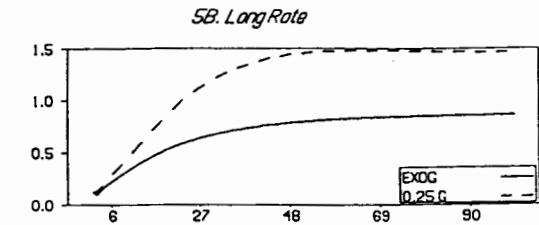
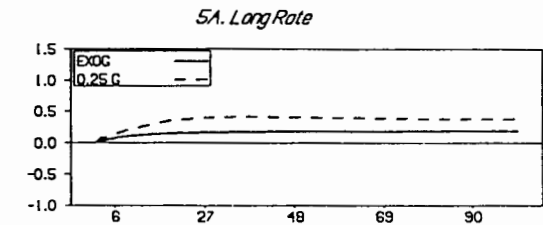
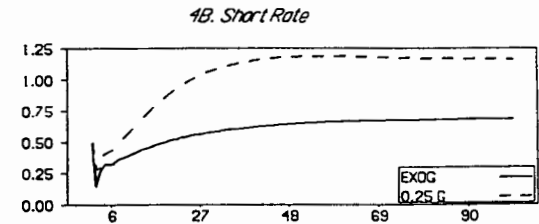
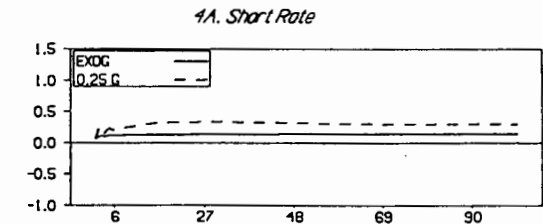
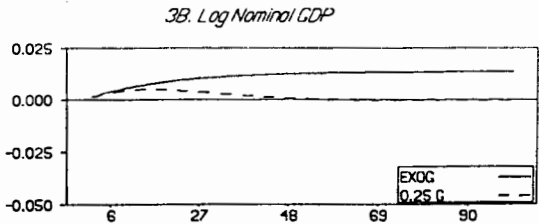
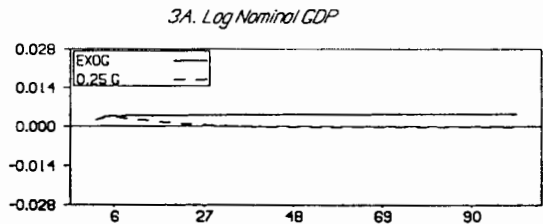
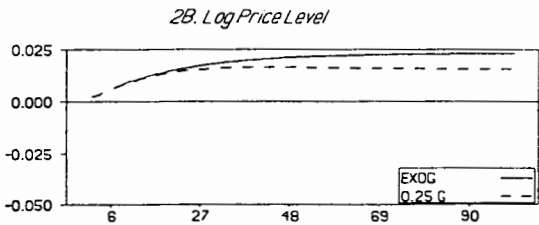
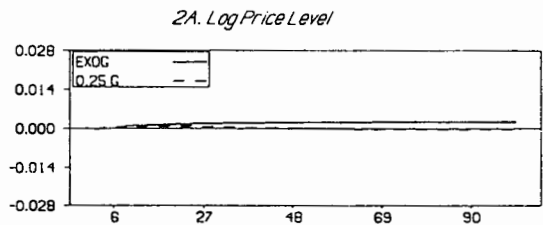
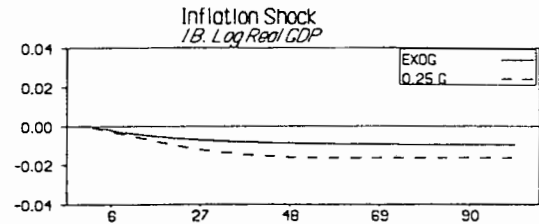
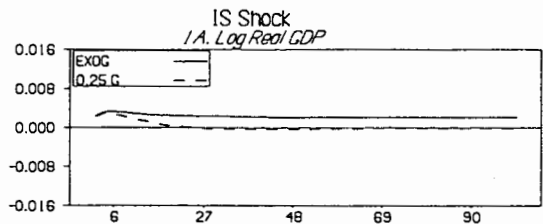


**Figure 9. Reduced-Form Model Impulse Responses**

(Solid Lines: Exogenous Monetary Base Growth  
 Dash Lines: McCallum's Rule,  $\lambda=0.35$ , Level Target)

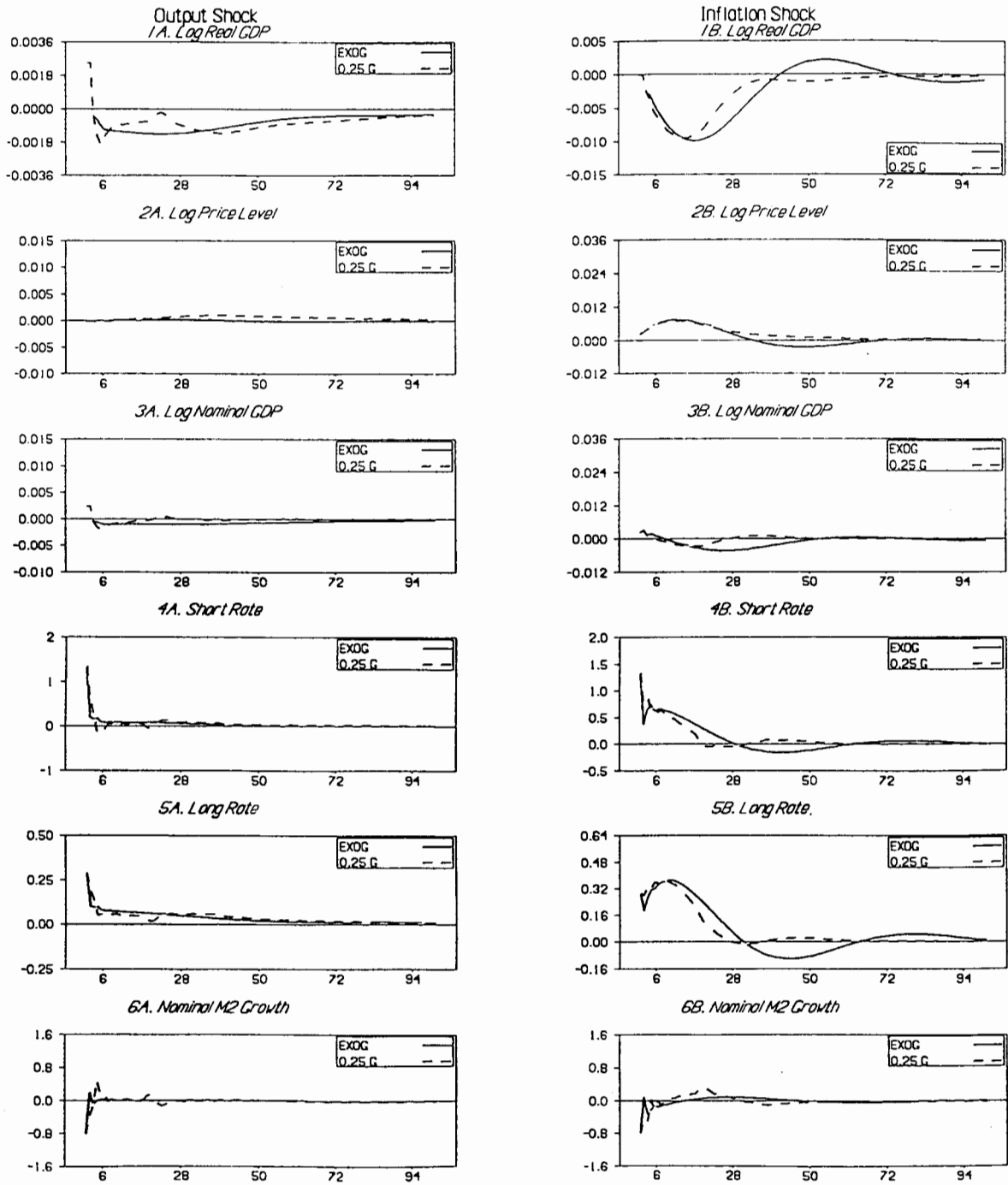


**Figure 10. Keynesian Model Impulse Responses**  
 (Solid Lines: Exogenous Monetary Base Growth  
 Dash Lines: McCallum's Rule,  $\lambda=0.25$ , Growth Target)



### Figure 11. Reduced-Form Model Impulse Responses

(Solid Lines: Exogenous Monetary Base Growth  
 Dash Lines: McCallum's Rule,  $\lambda = 0.25$ , Growth Target)



**Figure 12. Structural VAR Model Impulse Responses**

(Solid Lines: Exogenous Monetary Base Growth  
 Dash Lines: McCallum's Rule,  $\lambda = 0.25$ , Growth Target)

