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MONETARY POLICY RULES AND MACROECONOMIC STABILITY: EVIDENCE AND SOME THEORY

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Abstract

We estimate a forward-looking monetary policy reaction function for the postwar United States economy, before and after Volcker's appointment as Fed Chairman in 1979. Our results point to substantial differences in the estimated rule across periods. In particular, interest rate policy in the Volcker-Greenspan period appears to have been much more sensitive to changes in expected inflation than in the pre-Volcker period. We then compare some of the implications of the estimated rules for the equilibrium properties of inflation and output, using a simple macroeconomic model. The pre-Volcker rule is shown to be consistent with the possibility of persistent, self-fulfilling fluctuations in inflation and output. In contrast, the Volcker-Greenspan rule is stabilizing.

Keywords: monetary policy rules, business cycles, Taylor rules, sunspot fluctuations.

JEL Classification Numbers: E32, E52

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I. Introduction

From the late 1960s through the early 1980s, the United States economy experienced high and volatile inflation along with several severe recessions. Since the early 1980s, however, inflation has remained steadily low, while output growth has been relatively stable. Many economists cite supply shocks - and oil price shocks, in particular - as the main force underlying the instability of the earlier period. It is unlikely, however, that supply shocks, *by themselves*, could account for the observed differences between the two eras. For example, while jumps in the price of oil might help explain transitory periods of sharp increases in the general price level, it is not clear how they alone could explain persistent high inflation. Furthermore, as De Long [1997] argues, the onset of sustained high inflation occurred prior to the oil crisis episodes.

In this paper we explore the role of monetary policy. We first demonstrate that there is a significant difference in the way monetary policy was conducted pre- and post-1979, the year Paul Volcker was appointed Chairman of the Federal Reserve Board. We then go on to argue that this difference could be an important source of the shift in macroeconomic behavior. In some ways, our story should not be surprising. Many economists agree that monetary policy in the United States has been relatively well managed from the time Paul Volcker took over the helm, through the current regime of Alan Greenspan. It is also generally agreed that monetary policy was not so well managed in the fifteen years or so prior to Volcker.[1] The contribution of our paper is to add precision to this conventional wisdom.

We identify how monetary policy differed before and after Volcker came to office by estimating policy rules for each era. Specifically, we estimate a general type of rule that treats the Federal Funds rate as the instrument of monetary policy. The rule calls for adjustment of the Funds rate to the gaps between *expected* inflation and output and their respective target levels. It is a version of the kind of policy rule that emerges in both positive and normative analyses of central bank behavior that

[1] See, e.g., the recent discussions in Friedman and Kuttner [1996] and Gertler [1996].

have appeared in recent literature.[2] A distinctive feature of our specification is that it assumes forward-looking behavior on the part of the central bank.

The key difference in the estimated policy rules across time involves the response to expected inflation. We find (not surprisingly) that the Federal Reserve was highly "accommodative" in the pre-Volcker years: On average, it let real short term interest rates decline as anticipated inflation rose. While it raised nominal rates, it typically did so by less than the increase in expected inflation. On the other hand, during the Volcker-Greenspan era the Federal Reserve adopted a proactive stance toward controlling inflation: it systematically raised real as well as nominal short term interest rates in response to higher expected inflation. Our results thus lend quantitative support to the popular view that not until Volcker took office did controlling inflation become the organizing focus of monetary policy.

The second part of the paper presents a theoretical model designed to flesh out how the observed changes in the policy rule could account for the change in macroeconomic performance. We embed policy rules of the type we estimate within a fairly standard business cycle model and then analyze the dynamics of inflation and output in the resulting equilibrium. We show that the estimated rule for the pre-Volcker period permits greater macroeconomic instability than does the Volcker-Greenspan rule. Indeed, the pre-Volcker rule leaves open the possibility of bursts of inflation and output that result from self-fulfilling changes in expectations. These sunspot fluctuations may arise because under this rule because individuals (correctly) anticipate that the Federal Reserve will accommodate a rise in expected inflation by letting short term real interest rates decline.[3] As we show, within this environment persistent fluctuations in inflation and output can arise even in the absence of any fundamental

[2]See Clarida, Galí, and Gertler [1998a] for a review of the recent literature on monetary policy.

[3]Chari, Christiano and Eichenbaum (1997) also suggest that the inflation of the 1970s may have mainly been due to self-fulfulling behavior. Their argument exploits the idea that there may be a multiplicity of equilibria in reputational models of monetary policy. Our analysis is based simply on the implications of the estimated historical policy reaction function.

disturbances to the economy. These self-fulfilling fluctuations cannot occur under the estimated rule for the Volcker-Greenspan era since, within this regime, the Federal Reserve adjusts interest rates sufficiently to stabilize any changes in expected inflation.

The Volcker-Greenspan rule is also more effective than the pre-Volcker rule at mitigating the impact of fundamental shocks to the economy. That is, holding constant the volatility of exogenous fundamental shocks, the economy exhibits greater stability under the post-1979 rule than under a rule that closely approximates monetary policy pre-1979.

The plan of the paper is as follows. Section II presents our policy rule specification, and discusses the econometric procedure used to estimate it. Section III reports estimates of this rule for different sample periods, conducts a number of robustness checks, and identifies the main differences in the coefficient estimates across periods.

Section IV presents the theoretical model: a (now) conventional New Keynesian framework with money, monopolistic competition, and sticky prices. We then present both a qualitative and quantitative analysis of the model under the pre- and post 79 policy rules.

Section V offers concluding remarks. Here we discuss an important issue that the paper raises but does not resolve: why in the pre-Volcker period the Federal Reserve appeared to pursue a systematic policy rule that not only accommodated inflation, but did so in a way that was entirely predictable by the private sector (at least with the benefit of hindsight).

II. The Federal Reserve's Policy Reaction Function: A Forward Looking Model

A. A Simple Forward Looking Rule

We begin with a baseline specification of the policy reaction function. We take as the instrument of monetary policy the Federal Funds rate. Except possibly for a brief period of reserves targeting at the start of the Volcker era, this seems a reasonable choice (see, e.g., Bernanke and Mihov [1998]). Further, Goodfriend [1991] argues that even under the period of official reserves targeting, the Federal Reserve had in mind an implicit target for the Funds rate.

The baseline policy rule we consider takes a simple form. Let r_t^* denote the target rate for the nominal Federal Funds rate in period t. The target rate each period is a function of the gaps between expected inflation and output and their respective target levels. Specifically, we postulate the linear equation:

$$r_t^* = r^* + \beta \ (E[\pi_{t,k}|\Omega_t] - \pi^*) + \gamma \ E[x_{t,q}|\Omega_t] \quad (1)$$

where $\pi_{t,k}$ denotes the percent change in the price level between periods t and $t+k$ (expressed in annual rates). π^* is the target for inflation. $x_{t,q}$ is a measure of the average output gap between period t and $t+q$, with the output gap being defined as the percent deviation between actual GDP and the corresponding target.[4] E is the expectation operator, and Ω_t is the information set at the time the interest rate is set. r^* is, by construction, the desired nominal rate when both inflation and output are at their target levels.

The policy rule given by (1) has some appeal on both theoretical and empirical grounds. Approximate (and in some cases exact) forms of this rule are optimal for a

[4] The flow nature of GDP forces us to be more precise here: $x_{t,q}$ includes GDP generated between the beginning of period t and the beginning of period $t+q$ (i.e., it includes periods (e.g., quarters) t, $t+1$, ...and $t+q-1$). In our empirical work, we account for the fact that period t GDP is not known as of the time the interest rate is set in that period, i.e., $x_{t,1} \notin \Omega_t$. This is not true in our theoretical model of section IV, where all variables dated in period t are determined simultaneously.

central bank that has a quadratic loss function in deviations of inflation and output from their respective targets, given a generic macroeconomic model with nominal price inertia.[5]

On the empirical side, a number of authors have emphasized that policy rules like (1) provide reasonably good descriptions of the way major central banks around the world behave, at least in recent years. It is true that the most notable of these papers, Taylor [1993], proposes a rule where the Funds rate responds to lagged inflation and output rather than their expected future values. However, our forward looking rule nests the Taylor rule as a special case: If either lagged inflation or a linear combination of lagged inflation and the output gap is a sufficient statistic for forecasting future inflation then equation (1) collapses to the Taylor rule.[6] On the other hand, our forward looking specification allows the central bank to consider a broad array of information (beyond lagged inflation and output) to form beliefs about the future condition of the economy, a feature which we find highly realistic.

Finally, a forward looking rule like (1) is consistent with how Federal Reserve officials view the formulation of monetary policy: Consider for example the following quote by Chairman Alan Greenspan:

> "...current conditions should not be seen as a basis for monetary policy, only as an indicator of whether inflationary pressures might be starting to build.... What the Federal Reserve will have to judge is not so much the question of where prices are or have been, but rather what is the state of the economy later this year and into 1998 when any actions we may or may not have taken would become effective." (New York Times, March 21, 1997).

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[5]See, e.g., Svensson [1996], and Clarida, Galí, and Gertler [1998a].

[6]In this case, however, the estimated coefficients of the Taylor rule may be misleading as indicators of the Fed's intended response to inflation and output changes since, in addition to the size of the policy response, they capture the ability of each variable to forecast the state of the economy.

B. Implied Real Rate Rule

The implications of a policy rule like (1) for the cyclical behavior of the economy will of course depend on the sign and magnitude of the slope coefficients, β and γ. To gain the basic intuition, consider the implied rule for the (ex-ante) real rate target, rr_t^*:

$$rr_t^* = rr^* + (\beta - 1)\ (E[\pi_{t,k}|\Omega_t] - \pi^*) + \gamma\ E[x_{t,q}|\Omega_t] \tag{2}$$

where $rr_t^* \equiv r_t - E[\pi_{t,k}|\Omega_t]$ and where $rr^* \equiv r^* - \pi^*$ is the long run equilibrium real rate.[7] We assume that the real rate is stationary and is determined by non-monetary factors in the long run, consistent with conventional wisdom. Accordingly, rr^* is a constant and is independent of monetary policy.

As equation (2) makes clear, the sign of the response of the *real* rate target to changes in expected inflation and the output gap depends on whether β is greater or less than one and on the sign of γ, respectively. Roughly speaking, to the extent that lower real rates stimulate economic activity and inflation (as implied by standard macroeconomic models and as perceived by policymakers and market participants alike), interest rate rules characterized by $\beta > 1$ will tend to be stabilizing, while those with $\beta \leq 1$ are likely to be destabilizing or, at best, accommodative of shocks to the economy.[8] A similar logic applies to the sign of γ (i.e.e, stabilizing if $\gamma >$

[7] Note that rr_t^* is an "approximate" real rate since the forecast horizon for inflation will generally differ from the maturity of the short term nominal rate used as a monetary policy instrument.

[8] Another way to model accommodation of inflation would to be allow for endogenous adjustment of the target inflation rate, π^*. We view this approach as a sympathetic alternative to the one we take of focusing on whether the slope coefficient β is less than unity. We opt to treat π^* as a constant and instead let β characterize the degree of accommodation for two reasons: First, this approach has the advantage of parsimony - there is no need to model the adjustment of π^*. Second, as a matter of logic, it is a priori reasonable to treat π^* as constant since it is meant to reflect an optimum for inflation that is independent of current economic conditions. In our robustness exercises, however, we do let π^* vary within each sub-sample. To foreshadow, we find that the magnitude of β seems to do a better job of capturing the degree of accommodation than any time variation in π^*, consistent with the approach we take.

0; destabilizing if $\gamma \leq 0$). We thus have benchmarks ($\beta = 1, \gamma = 0$) to evaluate differences in the estimated policy rules across time

C. Interest Rate Smoothing and Exogenous Shocks

Absent any further modification, the policy reaction function given by equation (1) is too restrictive to describe actual changes in the Funds rate. There are at least three reasons why. First, the specification assumes an immediate adjustment of the actual Funds rate to its target level, and thus ignores the Federal Reserve's tendency to smooth changes in interest rates.[9] Second, it treats all changes in interest rates over time as reflecting the Federal Reserve's systematic response to economic conditions. Specifically, it does not allow for any randomness in policy actions, other than that associated with mis-forecasts of the economy. Third, it assumes that the Federal Reserve has perfect control over interest rates, i.e., it succeeds in keeping them at the desired level (e.g., through necessary open market operations).

We relax these assumptions by extending the model in a straightforward way. In particular we specify the following relationship for the *actual* Funds rate, r_t:

$$r_t = \rho(L)\, r_{t-1} + (1-\rho)\, r_t^* + v_t \tag{3}$$

where $\rho(L) = \rho_1 + \rho_2 L + ... + \rho_n L^{n-1}$, and where $\rho \equiv \rho(1)$. v_t is a zero mean exogenous interest rate shock, and the Funds rate target r_t^* is given by (1). Equation 3 postulates partial adjustment of the Funds rate to the target r_t^*. Specifically, each period the Federal Reserve adjusts the Funds rate to eliminate a fraction $(1-\rho)$ of the gap between its current target level and some linear combination of its past values. We interpret ρ as an indicator of the degree of smoothing of interest rate changes.

There are two different (but compatible) interpretations of the v shocks that preserve the spirit of the original model. First, these disturbances might reflect unfore-

[9] See also Rudebusch [1995] for evidence on the serial correlation of interest rate changes. Why this smoothing occurs is beyond the scope of this paper, though a number of explanations are found in the literature, including fear of disruption of financial markets (Goodfriend [1991]), or uncertainty about the effects of interest rate changes (Sack [1997]).

seen shocks to banks' demand for reserves that interfere with the Federal Reserves's ability to maintain its Funds rate target. Or, alternatively, they may capture deliberate decisions to deviate temporarily from the systematic rule (i.e., true "policy shocks").

Combining the partial adjustment equation (3) with the target model (1) yields the policy reaction function

$$r_t = (1-\rho)\ [rr^* - (\beta - 1)\pi^* + \beta\ \pi_{t,k} + \ \gamma\ x_{t,q}] + \rho(L)\ r_{t-1} + \varepsilon_t \qquad (4)$$

where $\varepsilon_t \equiv -(1-\rho)\ \{\beta\ (\pi_{t,k} - E[\pi_{t,k}|\Omega_t]) + \gamma\ (x_{t,q} - E[x_{t,q}|\Omega_t])\} + v_t$. Notice that the term in curly brackets is a linear combination of forecast errors and is thus orthogonal to any variable in the information set Ω_t.

Let $\mathbf{z}_t$ denote a vector of instruments known when r_t is set (i.e., $\mathbf{z}_t \in \Omega_t$), and orthogonal to the exogenous monetary shock v_t (i.e., $E\{\mathbf{z}_t v_t\} = 0$). Equation (4) then implies the set of orthogonality conditions

$$E\{\ [r_t - (1-\rho)\ (rr^* - (\beta-1)\pi^* + \beta\ \pi_{t,k} + \ \gamma\ x_{t,q}) + \rho(L)\ r_{t-1}]\ \mathbf{z}_t\} = 0 \qquad (5)$$

which provide the basis for the estimation of the parameter vector $(\alpha, \beta, \gamma, \rho)$, using the Generalized Method of Moments (Hansen [1982]), with an optimal weighting matrix that accounts for possible serial correlation in $\{\varepsilon_t\}$.[10] To the extent that the dimension of vector $\mathbf{z}_t$ exceeds four–the number of parameters being estimated–(5) implies some overidentifying restrictions that we can test in order to assess of the validity of our specification as well as the set of instruments used.

In the absence of further assumptions our approach only identifies the term $rr^* - (\beta - 1)\pi^*$, but not rr^* or π^* separately. Since target inflation π^* is of some interest in our characterization of monetary policy, we impose an additional restriction that permits us to identify and estimate this parameter. Specifically, we take the observed sample average as a measure of the equilibrium real rate rr^*, an assumption which we

[10]Note that, by construction, the first component of $\{\varepsilon_t\}$ follows an $MA(a)$ process, with $a = \max[k, q] - 1$, and will thus be serially correlated (unless $k = q = 1$).

view as providing a reasonable first approximation, given our sample size. Imposing this restriction directly in equation (5) allows us to estimate π^* jointly with the parameter vector $(\alpha, \beta, \gamma, \rho)$. To demonstrate robustness, however, we also report estimates of $(\alpha, \beta, \gamma, \rho)$ that do not impose this additional restriction.

Before proceeding we briefly address several econometric issues. First, our empirical analysis maintains the assumption that both inflation and the nominal interest rate are stationary. We view this assumption as reasonable for the postwar United States, even though the null of a unit root in either variable is often hard to reject at conventional significance levels, given the persistence of both series and the well known low power of unit root tests. In addition to its empirical plausibility, stationarity of both inflation and the nominal interest rate is also a property of many of the theoretical models that rationalize the use of the kind of policy rule considered here.[11] In our robustness analysis, however, we do allow for the possibility of drift in the trend rate of inflation by letting the target inflation rate vary across the regimes of different Federal Reserve chairmen.

Second, within any sample period it is important to have sufficient variation in inflation and output in order to identify the slope coefficients in the policy reaction function, as well as the target inflation rate π^*. Estimating the rule over a short sample can yield highly misleading results. Suppose, for example, that the Federal Reserve responds aggressively to large deviations of inflation from target but not to small deviations. Then by looking at a period where there is little variation in inflation, for example, one might mistakenly conclude that the Fed is not aggressive in fighting inflation. Alternatively, suppose a central bank confronting high inflation is in the process of rasing rates to engineering a disinflation. By estimating the rule only over the current period of high inflation, one might mistakenly conclude that the central bank has a high target inflation rate.[12] The subsamples we consider, however,

[11]See, e.g., Clarida, Gali and Gertler [1998a].

[12]The estimate of π^* will depend heavily on the sample mean of inflation.

appear to contain sufficient variation in both inflation and output[13].

III. The Federal Reserve's Policy Reaction Function: the Evidence

In this section we report estimates of the policy reaction function defined by equations (1) and (3). We accomplish two main objectives. First, we demonstrate the existence of a systematic relationship between the Funds rate and forecasts of future inflation and output along the lines suggested by our model. Second, we identify differences in the conduct of monetary policy pre- and post- 1979. We do so by estimating monetary policy rules for each era and performing tests of structural stability across periods.

The data are quarterly time series spanning the period 1960:1-1996:4. With one exception, we obtain the data from CITIBASE (mnemonics follow in parentheses). We use as the interest rate the average Federal Funds rate (`FYFF`) in the first-month of each quarter, expressed in annual rates. The baseline inflation measure is the (annualized) rate of change of the GDP deflator (`GDPP`) between two subsequent quarters. But we also report results using CPI (`PUNEW`) inflation. The baseline "output gap" measure is the series constructed by the Congressional Budget Office (CBO). We also use two alternative measures (described below) based on the detrended series for GDP (`GDPQ`) and the unemployment rate (`LHUR`). The instrument set includes lags of the Funds rate, inflation, and the output gap, as well as the same number of lags of commodity price inflation (`PSCCOM`), M2 growth (`FM2`), and the "spread" between the long-term bond rate (`FYGL`) and the 3-month Treasury Bill rate (`FYGM3`).[14]

[13] When we consider sub-sample stability of our estimates in section III we address the short sample problem by restricting some coefficients to be constant across the sample (in the cases where we cannot reject the coefficient is stable.)

[14] In closely related work, Orphanides [1997] estimates a reaction function using more direct measures of the Fed's perception of both the output gap and inflation, based on real time data. His results, by and large, confirm the results we obtain.

We divide the sample into two main subperiods. The first (60:1-79:2), encompasses the tenures of William M. Martin, Arthur Burns, and G. William Miller as Federal Reserve chairmen. The second (79:3-96:4) corresponds to the terms of Paul Volcker and Alan Greenspan. As we discussed in the introduction, these subperiods roughly correspond to the unstable and stable eras of recent macroeconomic history. This characterization, while simplistic, is clearly reflected in the data. Table I reports the standard deviation of inflation (levels and HP-detrended) and output (CBO gap and HP-detrended), for the two subperiods. The reduction in volatility appears substantial for each variable. Not surprisingly, the decline is more dramatic when we begin the second subperiod in 82:4, after Volcker disinflation, as the bottom row of the Table indicates.

A. Baseline Estimates

Table II reports GMM estimates of interest rate rule parameters π^*, β, γ, and ρ for each sample period, using the CBO output gap and GDP deflator inflation (baseline variables). The target horizon is assumed to be one quarter for both inflation and the output gap. (i.e., $k = q = 1$). Standard errors are reported in brackets. The right-most column reports the p-value associated with a test of the model's overidentifying restrictions (Hansen's J-test). The estimates are based on a specification of the interest rate rule with two lags of the interest rate ($n = 2$), which seemed to be sufficient to eliminate any serial correlation in the error term. Four lags of the instruments were used.

A number of interesting results stand out. Note first that the model is not rejected at conventional significance levels for any of the specifications or sample periods. The estimates of β and γ, further, generally have the expected sign and are significant in most cases. These estimates also point to substantial differences in the policy reaction function across periods. Most importantly, the estimate of β, the coefficient associated with expected inflation, is significantly below unity for the pre-Volcker period (0.83 with s.e. 0.07), and far greater than one for the Volcker-Greenspan period (2.15 with s.e 0.40). On the other hand, the estimates of γ–the coefficient measuring the sensitivity to the cyclical variable–are also significant in both periods, but only marginally so for the Volcker-Greenspan era.[15]

The estimates of the inflation target, π^*, seem quite plausible in all cases: roughly four and a quarter percent pre-Volcker and three and half percent post- Volcker. While the point estimates reveal a slight downward trend over time, the difference is not significant. Based on this result and the estimates of α and β across sub-samples, it does not seem to be the case that differences in monetary policy pre- and post-1979 reflect simply differences in the target inflation rate. We shortly present some more evidence that bears on this issue that stems from an analysis of (within) sub-sample stability.

Finally, the estimate of the smoothing parameter ρ is high in all cases, suggesting considerable interest rate inertia: Only between 10 and 30 percent of a change in the interest rate target is reflected in the Funds rate within the quarter of the change. Thus our estimates confirm the conventional wisdom that the Federal Reserve smooths adjustments in the interest rate.

To illustrate how well the model characterizes the behavior of the Funds rate, Figures I and II present the target rate estimates for each sub-period relative to the actual values of the Funds rate, using on our baseline estimates. In each sub-period, the target rate captures the broad swings in the actual rate reasonably well. Interestingly, during 1987-1992 period that Taylor (1993) analyzes, our target rate tracks the actual rate about as well as does the simple Taylor rule.[16]

B. Robustness Analysis

We next explore the robustness of our results along a number of dimensions. We consider: (1) alternative measures of inflation and the output gap; (2) alternative tar-

[15] See below for further discussion.

[16] We stress that we are comparing the actual rate to the implied target rate, as opposed to the fitted model, which allows for partial adjustment. The fitted model, of course, would track the actual rate even more closely than does the target rate.

get horizons for each variable; (3) relaxing the constraint on the intercept that allows us to identify π^*; (4) parameter stability within sub-samples; (5) a backward looking variation of our policy reaction function. We demonstrate that in each instance, the insights from the baseline case remain intact.

1. *Alternative Measures*

We first re-estimate the reaction function using different measures of the output gap and inflation. We consider two alternative measures of the output gap: (a) the deviation of (log) GDP from a fitted quadratic function of time; and (ii) the deviation of the unemployment rate from a similar time trend, with the sign of the resulting series switched.[17] Finally, we consider one alternative measure of inflation: the rate of change of the consumer price index (CPI).

Table III reports the estimates for the two main subperiods. The key results from the baseline case are robust to the use of alternative output gap and inflation measures. In fact, both the signs and magnitudes of the estimated parameters remain largely unchanged. There is, however, one minor difference: the estimated output gap coefficient for the Volcker-Greenspan subperiod, though positive, is now insignificant under the three specifications. At the same time, there remains a striking difference in the estimated slope coefficient for inflation across sub-periods: less than one before Volcker, greater than one under Volcker-Greenspan, with points estimates very close to those obtained in the baseline case.

2. *Alternative Horizons*

In the baseline case we assume that the Federal Reserve looks ahead one quarter for both inflation and the output gap. We now consider allowing for alternative–and, in our opinion, more realistic–target horizons for the same variables. Table IV reports results for ($k = 4$, $q = 1$) as well as ($k = 4$, $q = 2$), i.e. the Fed is assumed to have a target horizon of one year for its inflation target and of one (or two) quarters for the output. We view these values as roughly consistent with informal discussions of policy

[17] We switch the sign of the series in order to preserve the sign interpretation for parameter γ.

tactics by Federal Reserve officials..[18]. One formal rationale is that these horizons are roughly in line conventional wisdom regarding the lag with which monetary policy affects either variable. In either case, the results are qualitatively very similar to those reported in Table II.

3. *Unrestricted Intercept*

As we discussed, our approach identifies the inflation target π^* by assuming that the equilibrium real rate rr^* is known and equal to the observed average real rate over the relevant sample period. Here we relax that assumption and treat r^* as unobserved, at the cost of leaving π^* unidentified (only $\alpha \equiv rr^* - (\beta - 1)\pi^*$ is identified). Table V reports the estimates for the remaining parameters thus obtained. The only significant difference relative to our baseline estimates of Table II is given by the insignificance of the output gap coefficient when the rule is estimated for the full Volcker-Greenspan sample period. This finding is reminiscent of that obtained when variables other than the baseline were used (see Table III).

4. *Subsample Stability*

We next explore the stability of parameters within each sub-sample. Among other things, this exercise permits us to relax the assumption that the inflation target π^* is constant within the estimation period. It is conceivable, for example, that there was an upward shift in the target during the period of rising inflation in the 1970s.

A simple and natural way to proceed is to assume that the policy reaction function is stable during the tenure of the Federal Reserve chairman in charge at the time, but may vary across Chairmen. If we tack the brief period of Miller (78:1-79:3) on to Burns (70:1-78:1), then each sub-period may be divided into two regimes of roughly equal length. For the pre-1979 sample we thus have: Martin (60:1-69:4) and Burns-Miller (70:1-79:2). For the post-1979: Volcker (79:3-86:4) and Greenspan (87:1-96:4).

As discussed earlier, estimating the policy rule over short samples can generate imprecise estimates, given the limited number of observations. Accordingly, we adopt

[18]See, e.g., the quotation by Greenspan above.

the following procedure: We first estimate the reaction function for each baseline period (pre-Volcker or Volcker-Greenspan), but allowing for a shift across Chairmen in each of the coefficients (by means of appropriate dummies). Second, we re-estimate the rule after constraining all the parameters for which that shift was found to be insignificant in the first stage to be constant across Chairmen, while allowing for shifts in the remaining parameters. The resulting estimates are reported in Table VI. We present estimates for two different target horizons for inflation and the output gap: (1,1) and (4,1).[19]

Consider first the pre-Volcker period. Interestingly, no significant difference arises across Chairmen in either the value of the inflation target π^*, or in the inflation coefficient β. The point estimates for the inflation target (in the 5-7 percent range) are somewhat above the baseline estimates for the full pre-Volcker sample, though not significantly since the standard errors are now rather large. The estimated value for the inflation coefficient is below unity and is in line with the baseline estimates. The only notable departure from the baseline case is that the output gap coefficient is insignificant under Martin's tenure, but positive and significant under Burns and Miller.

Our procedure detects few robust differences across the Volcker and Greenspan eras. As in the pre-Volcker era, the estimates π^* and β are stable across chairmen. Estimates for each parameter, further, are close to those obtained in the baseline case. With a one-period horizon for both inflation and the output gap, the coefficient on the latter is close to zero (and insignificant) under Volcker, but is positive and significant under Greenspan. On the other hand, when the target horizon for inflation is four quarters, this difference vanishes. The estimated common value is positive and significant. In addition, the estimates under the (4,1) horizon point to a significant increase in the degree of smoothing of interest rate changes under Greenspan, as

[19]Since we also dummy all the instruments, we only use only two instrument lags in our subsample stability analysis, thus keeping the total number of instruments (and the degrees of freedom) comparable to the other specifications.

reflected in the significantly higher estimate of the parameter ρ.

As a final check on subsample stability we explore the effects of removing the first three years of the Volcker regime from the entire Volcker-Greenspan sample. As we discussed, over the period 1979:4 - 1982:4, the operating procedures of the Federal Reserve involved targeting non-borrowed reserves as opposed to the Federal Funds rate.[20] Note, however, that our specification allows for the possibility that non-borrowed reserves may be the policy instrument since it includes an error term in the interest rate equation which could reflect the effect of money demand shocks. In this instance, all that is being assumed is that the Fed sets non-borrowed reserves to achieve a target interest rate in expectation, as defined by the reaction function.[21] Nonetheless, we re-estimate the Volcker-Greenspan reaction function for the period 82:4-96:4, thus excluding the period of non-borrowed reserves targeting.[22] The corresponding results, for two alternative horizons, are shown in the bottom panel of Table VI.

Once again, the estimates of β–the coefficient associated with expected inflation–are above unity and not statistically different from the baseline case (though the estimate for the (1,1) horizon is noisy)[23]. On the other hand, the estimates of γ–the coefficient measuring the sensitivity to the cyclical variable–all become very small

[20] Bernanke and Mihov [1998] present evidence that over the 1979:10 - 1982 period non-borrowed reserves was the operating instrument of monetary policy, which accords with conventional wisdom. For the rest of the time they show it is reasonable to treat the Federal Funds rate as the instrument of monetary policy.

[21] As we noted earlier, Goodfriend (1991) argues forcefully that the Federal Reserve did indeed choose targets for non-borrowed reserves over this period ultimately with an objective for the path of the interest rate in mind.

[22] In a companion paper, Clarida, Gali and Gertler [1997b], we show that our baseline specification is robust to allowing for the possibility that the Fed may respond to money growth independently of its predictive power for inflation. That is, we reject the hypothesis that the Fed was targeting money growth. Our results are thus consistent with Friedman and Kuttner [1996].

[23] If we do not restrict the intercept to identify π^*, then the estimate of β is significantly above unity and tightly estimated for the $(1,1)$ horizon, as well as for the $(4,1)$ horizon.

and insignificant when we use post-82 data (in contrast with our results for the full Volcker-Greenspan period). Thus, here we cannot reject the hypothesis that the Fed has effectively pursued a "pure inflation targeting" policy.

In sum, the key insights obtained the baseline case are robust to allowing for structural changes across Chairmen. In particular, the striking difference in the reaction function across time is the rise in the slope coefficient on inflation from slightly less than unity pre-Volcker to around two in the Volcker-Greenspan era.

5. *Backward looking estimates*

We complete our robustness analysis by reporting the estimates for different subperiods of a backward looking rule of the sort considered by Taylor (1993). Our version of that rule corresponds to specification (4) with both k and q set to -1. Table VII reports the corresponding results. All the qualitative features of our baseline specification estimates seem to be hold here as well, suggesting that they are not inherent to the forward looking specification of the interest rate rule. While we view the forward looking specification as more plausible a priori, the insights also obtain from the backward looking specification.

C. Discussion of the Empirical Results

Overall, our estimates point to the existence of important differences across periods in the sensitivity of monetary policy. This result, further, appears to be a robust feature of the data. Specifically, during the pre-Volcker period, in response to forecastable inflationary pressures, the Federal Reserve tended to let real interest rates decline or, at best, did not try to raise them. In other words, while the central bank did raises nominal rates, it did not do so sufficiently to raise real rates.[24] This kind

[24] Our finding of a less than one-for-one adjustment of the nominal rate to changes in expected inflation is closely related to the finding of a strong negative correlation between the estimated expected inflation rate and the estimated real rate by Mishkin [1981] and others in the context of an exploration of the Fisher hypothesis. Interestingly, the sample period in Mishkin's paper ends in 1979:4, just one quarter after Volcker began his tenure as Fed chairman!. Furthermore, in subsequent work, Huizinga and Mishkin [1986] show formally that there is a shift in interest rate behavior before

of response clearly does not stabilize inflation under any plausible view of the linkages between real rates, aggregate demand, output, and inflation. Thus, according to our results, the persistent and volatile behavior of inflation in the pre-Volcker era may be partly due to the monetary rule in place, independently of the nature of the fundamental shocks which may have impinged on the economy during that period.

By way of contrast, under the Volcker-Greenspan regime, the Federal Reserve has substantially raised target real rates in the wake of an anticipated increase in inflation (on a two-for-one basis, according to a rough average of our point estimates). To the extent that a rise in the real rate slows down the level of economic activity and relieves inflationary pressures, the interest rate policy in the Volcker-Greenspan era provides a natural explanation for the stability of inflation experienced by the US economy in recent years.

In the next section we flesh out the implications of the differences in monetary policy pre- and post-Volcker, using a simple macroeconomic framework.

IV. Interest Rate Rules and Economic Fluctuations

In this section we analyze some of the macroeconomic implications of the estimated monetary policy reaction functions. We do so in the context of a monetary business cycle model with sticky prices. We first present the model's equilibrium conditions, and then analyze how the properties depend on the monetary policy rule in place. A comprehensive analysis of the quantitative properties of the model is beyond the scope of the present paper. Instead, we choose to focus our attention on a specific, but (in our opinion) rather important and fascinating issue, namely, the extent to which the change in the systematic component of monetary policy across the pre-Volcker and the Volcker-Greenspan eras may explain some of the differences in the degree of macroeconomic instability.[25]

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and after October 1979.

[25] Kerr and King [1995] and Bernanke and Woodford [1997] also analyze the possibility of endogenous fluctuations in the context of sticky price framework under an interest rate rule.

The baseline framework we use is a (now familiar) dynamic New Keynesian model. We also, however, discuss how some of the results extends to a more conventional macroeconomic model

A. A Business Cycle Model with Sticky Prices

Our baseline model is a version of the sticky price models found in King and Wolman [1996], Woodford [1996, 1998], and Yun [1996], among others. After log-linearization around a zero inflation steady state, the model's equilibrium conditions are summarized by the following equations (ignoring any constants):

$$\pi_t = \delta \ E[\pi_{t+1}|\Omega_t] + \lambda \ x_t \tag{6}$$

$$x_t = E[x_{t+1}|\Omega_t] - \frac{1}{\sigma} \ (r_t - E[\pi_{t+1}|\Omega_t] - z_t) \tag{7}$$

$$r_t^* = \beta \ E[\pi_{t+1}|\Omega_t] + \gamma \ x_t \tag{8}$$

$$r_t = \rho \ r_{t-1} + (1-\rho) \ r_t^* \tag{9}$$

Equation (6) describes the change in the aggregate price level as a function of expected future inflation and the output gap.[26] It can be derived from the aggregation of optimal price-setting decisions by monopolistically competitive firms, in an environment in which each firm adjusts its price with a constant probability in any given period.[27] Equation (7) combines a standard Euler equation for consumption with a market clearing condition.[28] It is often interpreted as an IS schedule, determining

[26] Strictly speaking, x represents the deviation of (log) output from its natural rate, where the latter variable is defined as the level of output that would obtain under fully flexible prices. See Woodford [1996] for details. Galí and Gertler [1998] present some evidence suggesting that (6) provides a good first approximation to the dynamics of inflation in the United States.

[27] Such a price-setting structure was first introduced by in Calvo [1983], and has been frequently adopted in macroeconomic applications as a simple, flexible way of introducing price stickiness. A similar forward-looking Phillips curve arises, however, under alternative price-setting assumptions (e.g., quadratic adjustment costs or deterministic time-dependent rules with staggered pricing).

[28] It assumes time-separable preferences with time discount factor δ, and a CRRA period-utility with relative risk aversion parameter σ.

the current output gap as a function of the ex-ante real rate and expected future output. In that context, the exogenous disturbance z_t summarizes the influence of any underlying real driving forces (e.g., technology, government purchases, etc.), and can be interpreted as the ex-ante real rate that would prevail under fully flexible prices.[29] Below it is assumed that $\{z_t\}$ follows an AR(1) process

$$z_t = \phi \, z_{t-1} + \varepsilon_t$$

where $|\phi| < 1$, and $\{\varepsilon_t\}$ is white noise.

Equations (8) and (9) specify the policy rule. They are the theoretical model's counterpart to (1) and (3). For simplicity, we restrict ourselves to the case of $k = q = 1$, and assume that all variables dated t or earlier belong to information set Ω_t.

B. Equilibrium Dynamics

We now present some results that are useful for characterizing how the monetary policy rule affects the dynamics of the model and, in particular, the circumstances under which it may open up the possibility of self-fulfilling fluctuations.

Define the vector of endogenous variables $\mathbf{v}_t = [\pi_t, x_t, r_{t-1}]'$. After using (8) to substitute for r_t^* in (9), and some rearranging, we can rewrite the equilibrium conditions (6)-(9) as a first-order difference equation:

$$E_t \, \mathbf{v}_{t+1} = A \, \mathbf{v}_t + B \, z_t \tag{10}$$

where A and B are matrices given by

$$A = \begin{bmatrix} \frac{1}{\delta} & -\frac{\lambda}{\delta} & 0 \\ \frac{\beta(1-\rho)-1}{\sigma\delta} & 1 + \frac{\lambda\,(1-\beta(1-\rho))}{\sigma\delta} + \frac{\gamma(1-\rho)}{\sigma} & \frac{\rho}{\sigma} \\ \frac{\beta(1-\rho)}{\delta} & \frac{(1-\rho)\,(\delta\gamma-\beta\lambda)}{\delta} & \rho \end{bmatrix} \qquad B = \begin{bmatrix} 0 \\ -\frac{1}{\sigma} \\ 0 \end{bmatrix}$$

As shown in Blanchard and Kahn [1980], the nature of the set of solutions to (10) hinges critically on the eigenvalues of A, and the fact that only one of the variables

[29] See Woodford [1998] for a detailed discussion of the interpretation of z.

in $\mathbf{v}_t$ is predetermined (the lagged interest rate). Let μ_1, μ_2, and μ_3 represent the eigenvalues of A. Let us assume, without lost of generality, that $|\mu_1| \geq |\mu_2| \geq |\mu_3|$.

Here we restrict our discussion to stationary, non-explosive solutions. There are two cases of interest.

Suppose first that $|\mu_1| \geq |\mu_2| > 1 > |\mu_3|$, i.e. the number of eigenvalues outside the unit circle equals the number of non-predetermined variables. In that case there exists a unique stationary equilibrium, in which π_t, x_t, and r_t are a uniquely determined by the history of fundamental shocks (i.e., by z_t, z_{t-1}, z_{t-2},...).[30]

Suppose, instead, that $|\mu_1| > 1 > |\mu_2| \geq |\mu_3|$, i.e., the number of eigenvalues outside the unit circle falls short of the number of non-predetermined variables. In that case the values π_t, x_t, and r_t can no longer be pinned down uniquely as a function of current and lagged values of fundamental shocks. In fact the nature of indeterminacy is twofold in that case.[31] First, the size and pattern of the dynamic response of the endogenous variables to a fundamental shock is indeterminate. Second, and perhaps more interestingly, inflation, output, and the interest rate may also respond to sunspots innovations, i.e., news unrelated to fundamentals which end up affecting the equilibrium path of the economy through its (self-fulfilling) effect on expectations. In fact, in that case the economy may display genuine stationary stochastic fluctuations around their steady state values, even in the absence of any shocks to fundamentals.[32] Such sunspot fluctuations, though stationary, are potentially very persistent, with the degree of persistence measured by the "highest" stable eigenvalue (i.e., μ_2).

Interestingly, in the case of one-dimensional indeterminacy considered here, the response of each endogenous variable to a sunspot shock is fully determined (up to scale). In fact, in the absence of shocks to fundamentals ($z_t = 0$, all t) we can

[30] See, e.g., Blanchard and Kahn [1980] for a detailed discussion.

[31] See Proposition 3 in Blanchard and Kahn [1980] and the related discussion in Galí [1998].

[32] Such fluctuations correspond to stationary sunspot fluctuations in the terminology of Woodford [1986].

represent the stationary equilibrium as

$$[\pi_t, x_t, r_t]' = \sum_{k=0}^{\infty} F_k \ \eta_{t-k}$$

where $\{\eta_t\}$ is a sequence of sunspot innovations satisfying the martingale-difference property (i.e., $E_t \ \eta_{t+1} = 0$, all t) and where $\{F_k, \ k = 0, 1, 2, ...\}$ is a sequence of (3×1) matrices uniquely determined (up to scale) by the parameters of the model.[33]

The number of stable/unstable eigenvalues of A (and, thus, the nature of the resulting equilibrium) depends, ultimately on the values taken by the model's exogenous parameters, including the three that characterize the interest rate rule (β, γ, and ρ). In the next two subsection we examine the role of the latter in determining the properties of the equilibrium. Our estimates suggest the possibility of indeterminacy or at best (given the imprecision of the estimates in some cases) near indeterminacy under the pre-Volcker rule. The Volcker-Greenspan rule, on the other hand, falls clearly in the determinate range. We explore the issue of indeterminacy in the next section, and near indeterminacy in the subsequent one.

C. Interest Rate Rules and Endogenous Fluctuations

Here we investigate the role of the interest rate rule as a possible source of indeterminacy and endogenous fluctuations. Our strategy consists in calibrating the simple model presented above and analyzing the properties of the dynamical system describing the corresponding equilibrium. First we assign some benchmark values to parameters σ, δ, and λ (i.e., parameters entering matrix A other than those describing the policy rule) similar to the ones used by other authors in the literature. Given these baseline values, we study the properties of the model's equilibrium under alternative settings for the parameters describing the interest rate rule. In particular, we examine the model's predictions under interest rate rules similar to those estimated using postwar United States data.

[33] See Clarida, Galí, and Gertler (1997) for details. The possibility of sunspot fluctuations in a model similar to ours but with no interest rate smoothing (and thus no predetermined variables) has been analyzed in Bernanke and Woodford (1997).

Our baseline parameter values are as follows. We set the (quarterly) discount factor δ to 0.99, implying an annual risk-free rate of 4 percent. We set σ–the coefficient of relative risk aversion–to be equal to 1, and λ–the output elasticity of inflation equal to 0.3.[34]

In Table VIII we report the range of values of β–the coefficient of expected inflation in the interest rate rule–for which we can rule out the possibility of endogenous fluctuations, given the baseline values for $(\sigma, \delta, \lambda)$ and alternative parameter configurations for γ–the output coefficient–and ρ–the interest smoothing parameter. Because of space limitations we just stress here some of the qualitative results that emerge. First, as anticipated by the intuition given in the introduction, whether β is greater or smaller than one largely determines whether an exogenous shift in expected inflation is validated or not by the response of the monetary authority and, thus, whether it is consistent or not with equilibrium.[35] Strictly speaking, that threshold value for β obtains exactly only when $\gamma = 0$, i.e., when there is no systematic response to output variations.[36] As we increase γ, the lower bound for β goes down, though the deviation from unity is quantitatively very small (and independent of ρ). Second, as shown in the table, the range of β values for which the equilibrium is unique also has an upper bound. In other words, an "excessive" response to changes in expected inflation may

[34] There is no widespread consensus on the value of λ. Values found in the literature range from 0.05 (Taylor [1980]) to 1.22 (Chari et al. [1996]). Following Woodford [1996], we choose the intermediate value 0.30, which is consistent with the empirical findings in Roberts [1995].

[35] We should stress that we are not considering some complications that may be introduced by fiscal policy (see. e.g., Leeper [1991] and Woodford [1996]). In particular, we are implicitly assuming that fiscal policy is "Ricardian" in the sense that the fiscal authority assumes responsibility for meeting the interest obligations on government debt. If this condition is not met, then determinacy is possible with $\beta < 1$. As Woodford [1996] shows, however, deficit shocks can be a source of real instability in this instance. Whether it is important to account for fiscal policy in interpreting the pre-1979 era is a issue deserving of further research, we think.

[36] Kerr and King [1995] also emphasize the significance of wether β is above or below unity for indeterminacy.

also lead to sunspot fluctuations.[37] That upper bound appears to be increasing in, and very sensitive to, the value of ρ. Notice, however, that for empirically plausible values of the latter (which is always above 0.5 in our estimates), that upper bound becomes largely irrelevant, since crossing it would require implausibly large increases in the real interest rate in response to a rise in expected inflation.

Finally, given the baseline values for the non-policy parameters, we compute the eigenvalues associated with two calibrations of the interest rate rule that are meant to be "representative" of the estimates obtained for the pre-Volcker and Volcker-Greenspan eras in the empirical work discussed above. In either case, we restrict ourselves to the point estimates of our baseline specification found in Table II. The eigenvalues for each set of estimates are reported in Table IX.

As one could anticipate from the results in Table VIII and the earlier discussion of our empirical findings, the estimated interest rate rules for the pre-Volcker period imply that only one eigenvalue of A is outside the unit circle; accordingly, one cannot rule out the possibility of self-fulfilling fluctuations in output and inflation under that policy regime. What do these sunspot fluctuations "look like"? Though the amplitude of those fluctuations is indeterminate (since it is given by the variance of the sunspot shock), the size of largest stable eigenvalue is close to one in both cases, suggesting very strong persistence. This is further illustrated in Figure III, which displays simulated time series for output, inflation and the nominal rate, using our baseline estimates of the pre-Volcker rule (first row of Table II), and given a sequence of i.i.d. sunspot shocks drawn from the standard normal distribution.

In order to get some intuition for the mechanisms underlying sunspot fluctuations in our model, Figure IV displays the impulse responses of several variables to a sunspot shock. The sunspot realization generates, on impact, an increase in expected inflation (as well as the anticipation of a slow return to its original level). Given the assumed policy rule, that forecast revision leads to a rise in the nominal rate,

[37] This is the case emphasized by Bernanke and Woodford [1997].

but the latter falls short of the increase in expected inflation throughout the entire adjustment process. As a result, the real rate shows a persistent decline, fueling an expansion in output and a rise in inflation, thus validating the initial increase in expected inflation. Over time, output gradually returns to trend, and so do the nominal rate and inflation, as well as the real rate.

By way of contrast, as the bottom panel of Table IX indicates, the estimated interest rate rule for the Volcker-Greenspan period generates two eigenvalues with modulus above one. As discussed above, this condition is sufficient to pin down the levels of output and inflation uniquely and, thus, to rule out any independent role for changes in expectations as a source of fluctuations. Under such a regime, macroeconomic fluctuations arise only in the presence of shocks to fundamentals.[38] In other words, the monetary policy rule in place is not, *in itself*, a source of macroeconomic instability.

D. Near-Indeterminacy and Fundamental Shocks

As we have just seen, the point estimates for the inflation and output gap coefficients during the pre-Volcker era fall within the indeterminacy region of the canonical model presented above. This is true for all specifications considered. In some cases, however, the standard errors for the estimate of β are too large to rule out the possibility that the true value is unity or slightly above.[39] In this borderline instance the economy is just outside the region of indeterminacy.

Even though sunspot fluctuations are not feasible in this case, however, the economy is still likely to be relatively unstable under this kind policy regime. A value of

[38] An analysis of the effectiveness and desirability of alternative interest rate rules in a version of our model augmented with shocks to fundamentals can be found in Rotemberg and Woodford [1997], among others.

[39] In fact, it is possible to find combinations of rule specifications and subperiods within the pre-Volcker era for which the point estimate for β is slightly above one (though not significantly so). We thank an anonymous referee for that observation, which encouraged us to conduct the robustness analysis found above.

β equal or just above unity suggests that the central bank comes close to fully accommodating inflationary pressures, by raising nominal rates to keep real rates roughly constant. The absence of a strong stabilizing adjustment of the real rate suggests, in turn, that fundamental shocks may generate considerable volatility in inflation and the output gap, at least relative to the Volcker-Greenspan type policy, where the central bank adjusts real rates in a strongly countercyclical manner.

We illustrate this issue in the context of our calibrated model. We set the persistence of the fundamental shock ϕ equal to 0.9. We also set both γ and ρ are at their estimated values for the pre-Volcker period under the baseline specification (i.e., 0.27 and 0.68, respectively). We then compute the implied standard deviation of inflation and the output gap, under alternative values of β between one and two (all of which are associated with a determinate equilibrium).

The results are reported in Table X. For ease of exposition, we normalize to unity the standard deviations corresponding to the calibration with $\beta = 2.0$. The results make it clear that the cyclical response of the economy to fundamental shocks is quite sensitive to the inflation coefficient, especially over the estimated range of values across the pre-Volcker and Volcker Greenspan periods. Thus, as β rises from to one to two the volatility of both output and inflation declines more than in half, a substantial reduction.

E. Explosive Paths in a Conventional Sticky Price Model

Thus far we have analyzed the issue of stability within a New Keynesian model. Since the empirical relevance of this framework is a matter of some controversy (see, e.g., Fuhrer and Moore [1995]), we also briefly look at the implications of our estimates within a more traditional macroeconomic model. Consider, thus, the following textbook framework consisting of a backward looking Phillips curve

$$\pi_t = \pi_{t-1} + \lambda \; x_{t-1} + u_t \tag{11}$$

and a "static" IS curve

$$x_t = -\frac{1}{\sigma}\left(r_t - E[\pi_{t+1}|\Omega_t]\right) + g_t \tag{12}$$

where u_t and g_t represent, respectively, *i.i.d.* supply and demand shocks. Let us assume, for simplicity, a forward looking interest rate rule characterized by strict inflation targeting:[40]

$$r_t = \beta\ E[\pi_{t+1}|\Omega_t] \tag{13}$$

As with the New Keynesian model, the dynamics of the system are particularly sensitive to the value of the feedback coefficient β. It is similarly true that a critical threshold for stability is $\beta > 1$. In this conventional framework, however, $\beta < 1$ simply leads to explosive behavior. Stationary self-fulfilling equilibria are not possible since inflation does not depend on expectations of the future.

To see how explosive dynamics may arise under a pre-Volcker type policy regime, first combine (11)–(13) to derive the implied law of motion for inflation:

$$\pi_t = \left(\frac{\sigma}{\sigma - \lambda(1-\beta)}\right)\ \pi_{t-1} + \left(\frac{\sigma\ \lambda}{\sigma - \lambda(1-\beta)}\right)\ g_{t-1} + u_t$$

It can be easily checked that the AR(1) process describing inflation is non-stationary whenever β belongs to the interval $\left[1 - \frac{2\sigma}{\lambda}, 1\right]$. In fact, the process is *explosive* if β lies inside that interval. If $\beta \in \left(1 - \frac{\sigma}{\lambda}, 1\right)$ (the more interesting case), the initial impact of either type of shock on inflation is further amplified over time through its induced effects on expected inflation and, thus, the ex-ante real rate. Of course, such an equilibrium path would become unsustainable in practice, and would presumably lead to a change in regime.

[40] The generalization to a rule of the form given by (8)-(9) is straighforward, though it complicates the algebra unnecessarily, given our goals.

V. Summary and Concluding Remarks

In this paper we have provided an empirical characterization of the systematic component of United States monetary policy in the postwar era. In order to do so, we have estimated a simple forward looking policy reaction function.

Our estimates point to a significant difference in the way monetary policy was conducted pre and post late 1979. In the pre-Volcker years, the Fed typically raised nominal rates by less than any increase in expected inflation, thus letting real short term rates decline as anticipated inflation rose. On the other hand, during the Volcker-Greenspan era the Fed raised real as well as nominal short term interest rates in response to higher expected inflation. Thus, our results lend quantitative support to the view that the anti-inflationary stance of the Fed has been stronger in the past two decades.

Finally, we have argued that the pre-Volcker rule may have contained the seeds of macroeconomic instability that seemed to characterize the late 60s and 70s. In particular, we have shown that in the context of a calibrated sticky price model, the pre-Volcker rule leaves open the possibility of bursts of inflation and output that result from self-fulfilling changes in expectations. At best, the pre-Volcker rule does a considerably worse job than the Volcker-Greenspan policy of insulating the economy from fundamental shocks.

One important question our paper raises but does not answer is the following: Why is it that during the pre-1979 period the Federal Reserve followed a rule that was clearly inferior ?. Another way to look at the issue is to ask why it is that the Fed maintained persistently low short term real rates in the face of high or rising inflation. One possibility, emphasized by De Long [1997], is that the Fed thought the natural rate of unemployment at this time was much lower than it really was (or equivalently, that the output gap was much smaller). There is considerable anecdotal evidence to support this interpretation, though it is not clear why the Fed should have held this view over such a long period of time.

Another somewhat related possibility is that, at that time, neither the Fed nor the economics profession understood the dynamics of inflation very well.[41] Indeed, it was not until the mid-to-late 1970s that intermediate textbooks began emphasizing the absence of a long run trade-off between inflation and output. The ideas that expectations may matter in generating inflation and that credibility is important in policy-making were simply not well established during that era. What all this suggests is that in understanding historical economic behavior, it is important to take into account the state of policy-maker's knowledge of the economy and how it may have evolved over time. Analyzing policy-making from this perspective, we think, would be a highly useful undertaking.[42]

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[41] See, e.g., Croushore [1996] for evidence of systematic bias in inflation forecasts during that period.

[42] Some recent work in that direction can be found in Sargent [1998].

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TABLE I

AGGREGATE VOLATILITY INDICATORS

	Standard Deviation of:			
	Inflation		**Output**	
	level	*hp*	*gap*	*hp*
Pre-Volcker	2.77	1.48	2.71	1.83
Volcker-Greenspan	2.18	0.96	2.36	1.49
post-82	1.00	0.79	2.06	1.34

TABLE II
BASELINE ESTIMATES

	π^*	β	γ	ρ	p
Pre-Volcker	4.24	0.83	0.27	0.68	0.834
	(1.09)	(0.07)	(0.08)	(0.05)	
Volcker-Greenspan	3.58	2.15	0.93	0.79	0.316
	(0.50)	(0.40)	(0.42)	(0.04)	

Standard errors reported in brackets. The set of instruments includes four lags of inflation, output gap, the federal funds rate, the short-long spread, commodity price inflation and wage inflation.

TABLE III
ALTERNATIVE VARIABLES

	π^*	β	γ	ρ	p
Detrended Output					
Pre-Volcker	4.17	0.75	0.29	0.67	0.801
	(0.68)	(0.07)	(0.08)	(0.05)	
Volcker-Greenspan	4.52	1.97	0.55	0.76	0.289
	(0.58)	(0.32)	(0.30)	(0.05)	
Unemployment Rate					
Pre-Volcker	3.80	0.84	0.60	0.63	0.635
	(0.87)	(0.05)	(0.11)	(0.04)	
Volcker-Greenspan	4.42	2.01	0.56	0.73	0.308
	(0.44)	(0.28)	(0.41)	(0.05)	
CPI					
Pre-Volcker	4.56	0.68	0.28	0.65	0.431
	(0.53)	(0.06)	(0.08)	(0.05)	
Volcker-Greenspan	3.47	2.14	1.49	0.88	0.138
	(0.79)	(0.52)	(0.87)	(0.03)	

Standard errors reported in brackets. The set of instruments includes four lags of inflation, output gap, the federal funds rate, the short-long spread, commodity price inflation and wage inflation.

TABLE IV

ALTERNATIVE HORIZONS

	π^*	β	γ	ρ	p
k=4, q=1					
Pre-Volcker	3.58	0.86	0.34	0.73	0.835
	(1.42)	(0.05)	(0.08)	(0.04)	
Volcker-Greenspan	3.25	2.62	0.83	0.78	0.876
	(0.23)	(0.31)	(0.28)	(0.03)	
k=4, q=2					
Pre-Volcker	3.32	0.88	0.34	0.73	0.833
	(1.80)	(0.06)	(0.09)	(0.04)	
Volcker-Greenspan	3.21	2.73	0.92	0.78	0.886
	(0.21)	(0.34)	(0.31)	(0.03)	

Standard errors reported in brackets. The set of instruments includes four lags of inflation, output gap, the federal funds rate, the short-long spread, commodity price inflation and wage inflation.

TABLE V

UNRESTRICTED INTERCEPT

	α	β	γ	ρ	p
Pre-Volcker	2.19	0.68	0.28	0.65	0.431
	(0.29)	(0.06)	(0.08)	(0.05)	
Volcker-Greenspan	-0.27	2.14	1.49	0.88	0.138
	(1.66)	(0.52)	(0.87)	(0.03)	

Standard errors reported in brackets. The set of instruments includes four lags of inflation, output gap, the federal funds rate, the short-long spread, commodity price inflation and wage inflation.

TABLE VI
SUBSAMPLE STABILITY

	π^*	β	γ	ρ	p
Martin					
(1,1)	5.16	0.86	**0.14**	**0.77**	0.524
	(1.72)	(0.08)	(0.16)	(0.06)	
(4,1)	7.15	0.92	**0.06**	0.72	0.719
	(5.55)	(0.08)	(0.07)	(0.05)	
Burns-Miller					
(1,1)	5.16	0.86	**0.78**	**0.69**	0.524
	(1.72)	(0.08)	(0.18)	(0.04)	
(4,1)	7.15	0.92	**1.24**	0.80	0.719
	(5.55)	(0.08)	(0.39)	(0.05)	
Volcker					
(1,1)	3.75	2.02	**-0.02**	0.63	0.612
	(0.28)	(0.23)	(0.15)	(0.04)	
(4,1)	2.45	2.38	0.68	**0.74**	0.804
	(0.47)	(0.35)	(0.30)	(0.04)	
Greenspan					
(1,1)	3.75	2.02	**0.99**	0.63	0.612
	(0.28)	(0.23)	(0.18)	(0.04)	
(4,1)	2.45	2.38	0.68	**0.91**	0.804
	(0.47)	(0.35)	(0.30)	(0.02)	
Post-82					
(1,1)	3.43	1.58	0.14	0.91	0.416
	(1.24)	(0.72)	(0.42)	(0.03)	
(4,1)	3.16	3.13	0.09	0.82	0.894
	(0.10)	(0.33)	(0.15)	(0.02)	

Standard errors reported in brackets. The set of instruments includes two lags of inflation, output gap, the federal funds rate, the short-long spread, commodity price inflation, and wage inflation, as well as the same variables with a multiplicative subperiod dummy.

TABLE VII

BACKWARD LOOKING ESTIMATES

	π^*	β	γ	ρ	p
Pre-Volcker	5.95	0.86	0.39	0.68	0.590
	(1.92)	(0.07)	(0.08)	(0.05)	
Volcker-Greenspan	4.08	1.72	0.34	0.71	0.307
	(0.56)	(0.28)	(0.19)	(0.05)	
Post-82	2.96	2.55	-0.15	0.89	0.486
	(0.27)	(0.56)	(0.28)	(0.03)	

Standard errors reported in brackets. The set of instruments includes four lags of inflation, output gap, the federal funds rate, the short-long spread, commodity price inflation and wage inflation.

TABLE VIII
INDETERMINACY ANALYSIS

	$\rho = 0$	$\rho = 0.5$	$\rho = 0.9$
$\gamma = 0$	1.0, 14.2	1.0, 42.9	1.0, 272
$\gamma = 0.5$	0.983, 17.5	0.983, 46.2	0.983, 275
$\gamma = 1$	0.966, 20.9	0.966, 49.5	0.966, 278

For each pair of (γ, ρ) values the Table reports the interval of β values for which the equilibrium exists and is unique.

TABLE IX

EIGENVALUES FOR CALIBRATED MODEL

	$\|\mu_1\|$	$\|\mu_2\|$	$\|\mu_3\|$
Pre-Volcker	1.59	0.95	0.45
Volcker-Greenspan	1.42	1.30	0.42
Post-82	1.58	1.06	0.54

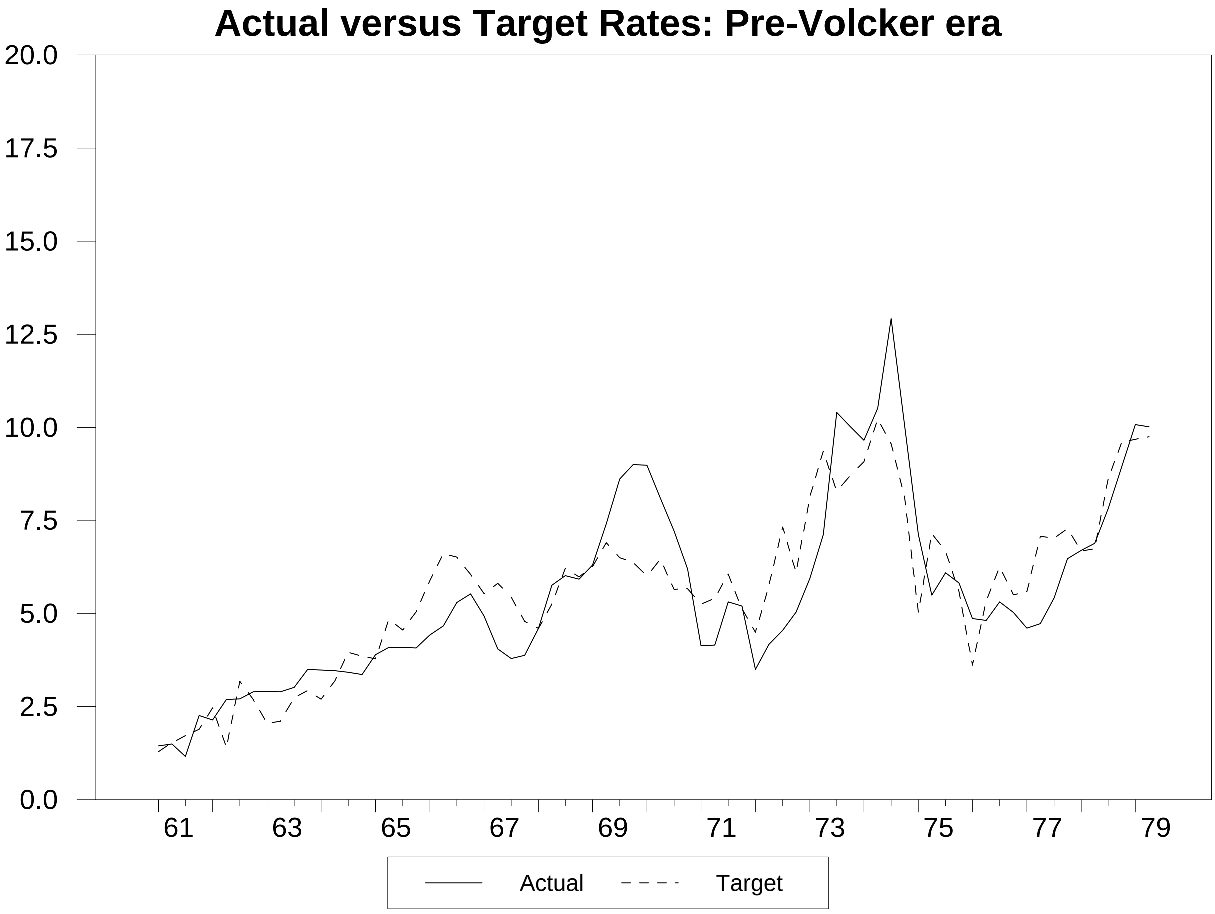
Each row reports the three moduli of the eigenvalues of matrix A implied by the calibrated model, using baseline estimates of (β, γ, ρ) for each period, found in Table II.

TABLE X

FUNDAMENTAL SHOCKS

	Standard Deviation of:	
β	**Inflation**	**Output gap**
2.0	1.00	1.00
1.5	1.48	1.36
1.1	2.57	2.16
1.0	3.20	2.61

Figure I



Actual versus Target Rates: Pre-Volcker era
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
61
63
65
67
69
71
73
75
77
79
Actual
Target

Figure II

Actual versus Target Rates: Volcker-Greenspan era

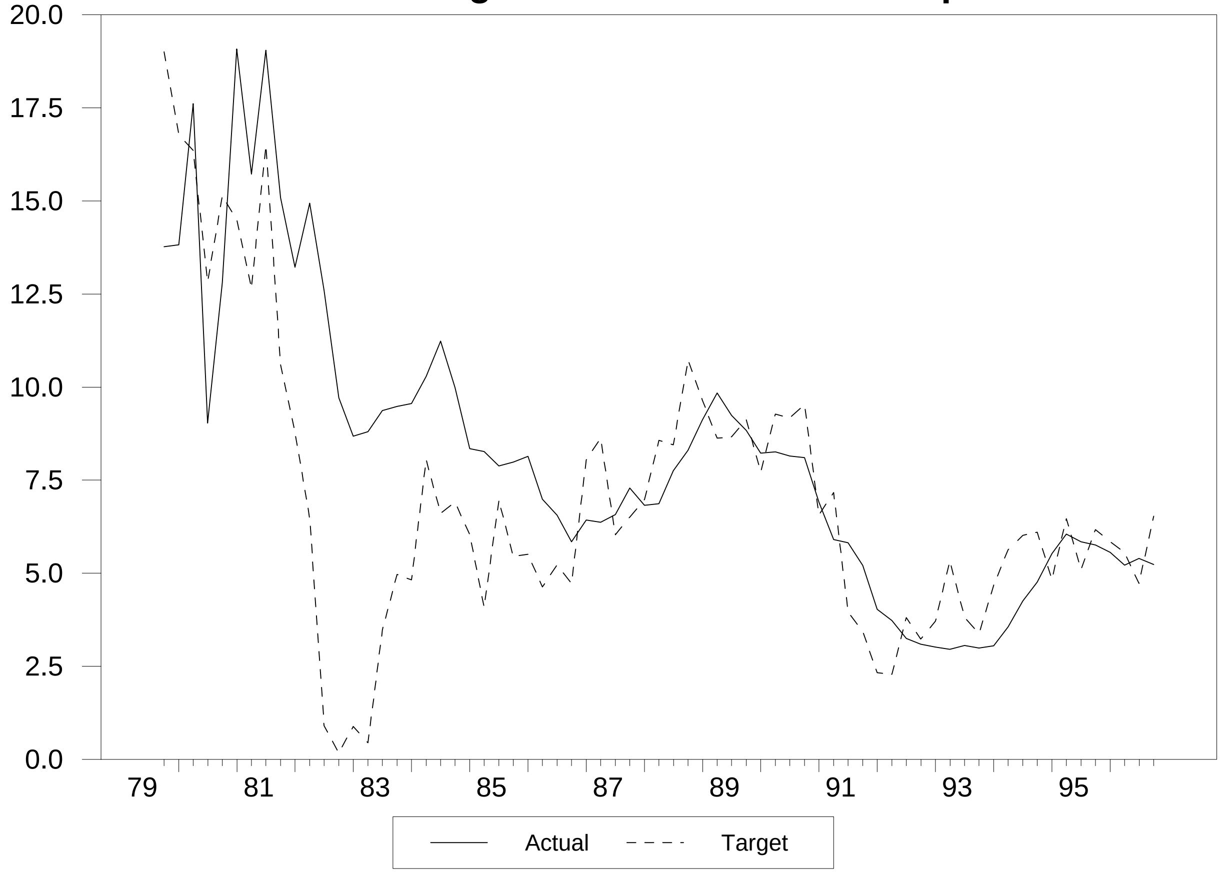


Figure III. Simulated Sunspot Fluctuations under Pre−Volcker Rule

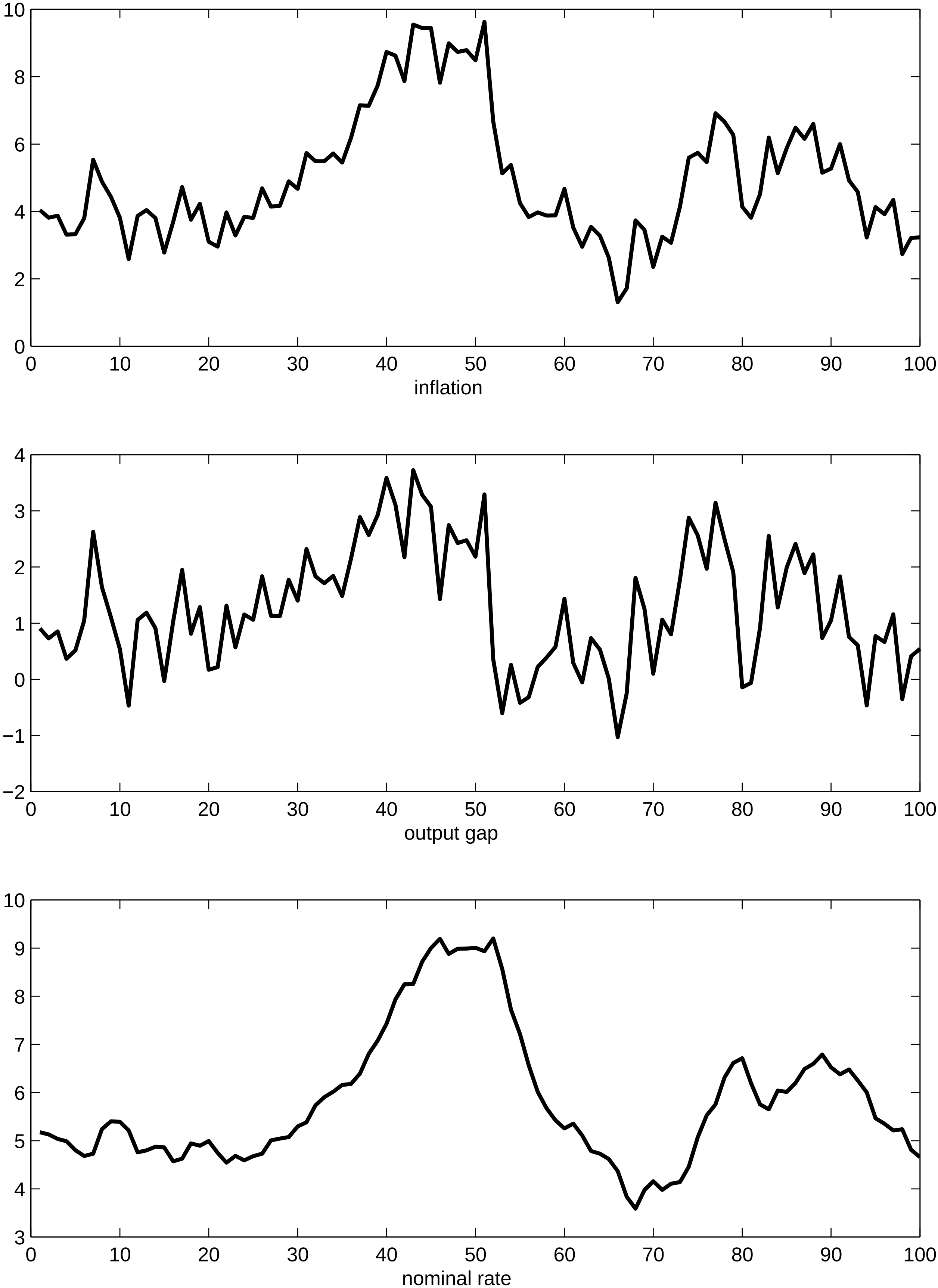


Figure IV. Impulse Responses to a Sunspot Shock