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AND MACROECONOMIC STABILITY:
EVIDENCE AND SOME THEORY

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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 U.S economy, pre- and post-October 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.

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1. Introduction

From the late 1960s through the early 1980s, the U.S. 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 a rise in the price of oil may 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 DeLong (1996) 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 October 1979. We then go on to argue that this difference in policy behavior could be an important underlying source of the shift in macroeconomic behavior. In some ways, our story should not be surprising. Many economists agree that U.S. monetary policy has been relatively well managed from the time Paul Volcker took over the helm in late 1979 and 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, however, is to spell out some key differences in the way monetary policy was conducted and to analyze how tnese differences could have contributed to the

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

shift in macroeconomic performance.

We identify how monetary policy differed before and after the Volcker policy shift 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 have appeared in recent literature.[2] A distinctive feature of our interest rate rule specification is that it assumes forward-looking behavior on the part of the central bank.

The key difference in the estimated policy rules involves the response to expected inflation. We find (not surprisingly) that the Federal Reserve was "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 estimated previously within a fairly standard business cycle model and then analyze the

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[2] See Clarida, Gali and Gertler (1997a) for a review of recent literature.

statistical properties of inflation and output. We show that the estimated rule for the pre-Volcker period permits greater macroeconomic instability than does the Volcker-Greenspan rule. In particular, 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 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 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.

Section 2 below presents estimates of the reaction function for the Federal Funds rate across different sample periods. In doing so, we must confront two issues. First, the right hand side variables in the reaction function contain expected inflation and expected output, which are not directly observable. Second, there is potential simultaneity bias: the Funds rate responds to anticipated inflation and output but, in turn, may affect these variables. To address this issues, we use a novel procedure for estimating policy reaction functions based on GMM.

Section 3 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-

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[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.

and post 79 policy rules.

Section 4 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.).

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

2.1. A Simple Forward Looking Rule

We begin with a baseline specification of the Fed's 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 (1997)). 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 is determined each period as a function of the gaps between expected inflation and output and their respective target levels. Specifically, we postulate the linear equation:

$$r_t^* = \alpha + \beta \ (E[\pi_{t,k}|\Omega_t] - \pi^*) + \gamma \ E[x_{t,q}|\Omega_t] \tag{2.1}$$

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 Fed 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 Fed target. E is the expectational operator, and Ω_t is the information set at the time the interest rate is set. α is, by construction, the desired nominal rate when both inflation and output are at their target levels.[4]

The policy rule given by (2.1) has some appeal on both theoretical and empirical grounds. Approximate (and in some cases exact) forms of this rule are optimal for a central bank that has a quadratic loss function in deviations of inflation and output from their respective targets in a generic macro model with price inertia.[5]

On the empirical side, a number of authors have emphasized that policy rules like (2.1) 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 (1994), 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 (2.1) collapses to the Taylor rule. In this case, however, the estimated coefficients may be misleading as indicators of the Fed's intended response to inflation and output changes

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[4] The flow nature of GDP forces us to be more precise here: $x_{t,q}$ includes GDP generated between the beginning of period (e.g., quarter) t and the beginning of period $t+q$ (i.e., it includes periods (e.g., quarters) t, $t+1, \ldots$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 4, where all variables dated in period t are determined simultaneously.

[5] See, e.g., Svensson (1996), Bernanke and Woodford (1997), and Clarida, Galí, and Gertler (1997a).

since, in addition to the size of the response, they will be capturing the ability of each variable to forecast the state of the economy. 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, we believe a forward looking rule like (2.1) fits common characterizations of Fed monetary policy provided by policymakers themselves, in speeches or other public policy statements, as illustrated by the following quote by Fed 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).

2.2. Implied Real Rate Rule

Needless to say, the implications of a policy rule like (2.1) on the behavior of the economy will depend, both in theory and in practice, on the sign and magnitude of coefficients α, β and γ. Some basic intuition for the likely implications may be gathered by writing down the implied rule for the (ex-ante) real rate target:

$$rr_t^* = \widetilde{\alpha} + (\beta - 1)\ (E[\pi_{t,k}|\Omega_t] - \pi^*) + \gamma\ E[x_{t,q}|\Omega_t] \tag{2.2}$$

where $rr_t^* \equiv r_t - E[\pi_{t,k}|\Omega_t]$ and $\widetilde{\alpha} \equiv \alpha - \pi^*$.[6]

Equation (2.2) provides several insights. First, the requirement that the output and inflation targets are attained "on average," together with the (conventional) assumption that the real rate is determined by non-monetary factors in the long-run, implies a constraint on α which must thus be set equal to the exogenously given long term "equilibrium" real rate plus the inflation target π^*.

Most interestingly, and as equation (2.2) 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, and to the extent that lower real rates stimulate economic activity and inflation (as implied by many standard macro 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 $\beta < 1$ are expected to be destabilizing. A similar logic would seem to apply to the sign of γ. As it will become clear below, these observations provide the key to some of our results of section 4.

2.3. Interest Rate Smoothing and Exogenous Shocks

The specification of the Fed's reaction function introduced above is too restrictive to be useful as a model for changes in the actual Funds rate. There at least three reasons for this. First, it assumes an immediate adjustment of the actual Funds rate to its target level in response to a change in the latter called for by the rule, and thus ignores the Federal Reserve's tendency to smooth changes

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[6] Note that rr_t^* is an approximate real rate since the forecast horizon for inflation may differ from the maturity of the short term nominal rate.

in interest rates.[7]Second, changes in interest rates over time are assumed to be purely endogenous, i.e., to reflect the Fed's systematic response to the inflation and output outlook. Third, it assumes that the Fed has perfect control over interest rates, i.e., it succeeds in keeping them at the desired level (e.g., through necessary open market operations).

A straightforward extension of our model allows us to relax those assumptions, thus increasing its chances to provide a good fit of the data. In particular we specify the following model for the *actual* Funds rate, r:

$$r_t = (1-\rho)\ r_t^* + \rho\ r_{t-1} + v_t \tag{2.3}$$

where $\rho \in [0,1)$ is an indicator of the degree of smoothing of interest rate changes, v_t is a zero mean exogenous interest rate shock, and the Funds rate target r_t^* is given by (2.1). Thus, our specification assumes a partial adjustment of the Funds rate to eliminate a fraction $(1-\rho)$ of the gap between last period's funds rate and its current target level. On the other hand, two different (but compatible) interpretations can be given to the v shocks, while sticking to the spirit of the original model. First, they may reflect the Fed's failure to keep the interest rate at the level prescribed by its rule, as it would be the case in the presence of money demand shocks if a variable other than the Funds rate were to be used as a monetary policy instrument. Or, alternatively, they may capture deliberate decisions to deviate transitorily from its systematic rule (i.e., true "policy shocks").

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[7] 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)).

Combining the partial adjustment equation (2.3) with the target model (2.1) yields the interest rate equation

$$r_t = (1-\rho)\ \widetilde{\alpha} + (1-\rho)\ \beta\ \pi_{t,k} + (1-\rho)\ \gamma\ x_{t,q} + \rho\ r_{t-1} + \varepsilon_t \tag{2.4}$$

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 (2.4) implies the set of orthogonality conditions

$$E\{[r_t - (1-\rho)\ \alpha - (1-\rho)\ \beta\ \pi_{t,k} - (1-\rho)\ \gamma\ x_{t,q} - \rho\ r_{t-1}]\ \mathbf{z}_t\} = 0 \tag{2.5}$$

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 $\{\varepsilon_t\}$.[8]To the extent that the dimension of vector $\mathbf{z}_t$ exceeds four–the number of parameters being estimated–(2.5) 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.

Before we proceed we briefly address a couple of econometric issues. First, our econometric analysis maintains the assumption that both inflation and the nominal interest rate are stationary, an assumption that we view as reasonable for the postwar U.S, even though the null of a unit root in either variables is

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[8] 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 $k = q = 1$).

often hard to reject at conventional significance levels in small samples like ours, 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 most of the theoretical models that rationalize the rule considered here.[9]Second, we wish to stress that within any sample period it is important to have sufficent variation in inflation and output in order to identify the slope coefficients in the policy reaction function. Suppose the Federal Reserve responds aggresively 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. The sub-samples we consider, however, contain substantial variation in both inflation and output.

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

In this section we report a number of estimates of the forward looking interest rate rule. Our objectives here are twofold. First, we document 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 try to identify possible differences in the conduct of monetary policy pre- and post- 1979. This leads us to estimate monetary policy rules for each era and to perform tests of structural stability across periods.

Our baseline estimates use quarterly time series spanning the period 1960:1-

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[9] See Clarida, Gali and Gertler (1997a).

1996:4. We divide the sample into two main sub-periods. The first (60:1-79:2), encompasses the tenures of Martin, Burns, and Miller as Fed chairmen. The second (79:3-96:4) corresponds to the Volcker-Greenspan era. All the data were drawn from CITIBASE (mnemonics are listed in parentheses in what follows). Our interest rate variable is the average federal funds rate (`FYFF`) in the first-month of each quarter, expressed in annual rates. Our inflation measure is the (annualized) rate of change of the GDP deflator (`GDPP`) between two subsequent quarters.[10] Our "output gap" series is constructed as the deviation of the logarithm of GDP (`GDPQ`) from a fitted quadratic function of time. We also report results based on deviation of the unemployment rate from a similar time trend, in which case we define $x_t \equiv -(u_t - u_t^*)$, where u_t corresponds to the unemployment rate (`LHUR`) in the first month of quarter t, and where the minus sign is added in order to preserve the sign interpretation for parameter γ. Our instrument set includes four 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`).[11]

3.1. Estimates of a Baseline Model

Table 1 reports GMM estimates of coefficients β, γ, and ρ of the interest rate rule for each sample period, using both (detrended) GDP and unemployment as

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[10] As discussed below, results based on the rate of change of the CPI (`PUNEW`) were almost identical, and are thus not reported.

[11] 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.

proxies for the output gap. 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 bottom panel shows the p-values associated with the null hypothesis of a common coefficient across subsample periods.

A number of interesting results stand out. First, the model is not rejected at conventional significance levels for any of the specifications or sample periods.[12] Second, the estimate of the smoothing parameter ρ is high, suggesting a lot of interest rate inertia, but not significantly different across periods. Third, all the estimates for β and γ have the expected sign, and are significant in most cases. Furthermore, those estimates point to substantial differences in the Fed's reaction function across periods. Most noticeably, the estimate of β, the coefficient associated with expected inflation, is below unity for the pre-Volcker period (point estimates are 0.80 and 0.73), and far greater than one for the Volcker-Greenspan period (1.80 and 1.77). In both cases the null of a unit coefficient is easily rejected, as is (not surprisingly) that of a common coefficient value across the same periods. On the other hand, the estimates of γ–the coefficient measuring the sensitivity to the cyclical variable–also differ across periods, though less dramatically: the null of a common value across can only be rejected with significance levels of 0.19 and 0.10. There is, however, one feature which seems particularly interesting: γ

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[12] In some preliminary work not reported here we also estimated a version of the model without partial adjustment (i.e., with $\rho = 0$). The overidentifying restriction were systematically rejected for all sample periods, at very low significance levels (p values less than 0.001). Those results led us to abandon the immediate adjustment specification and to focus instead on model with partial adjustment, which seems to fit the data much better.

appears to be significantly different from zero only for the pre-Volcker period. In other words, we cannot reject the hypothesis that under Volcker and Greenspan the Fed has effectively pursued a "pure inflation targeting" policy.

3.2. Alternative Horizons

As a first robustness check, we compute analogous estimates for alternative and, in our opinion, more realistic–target horizons for inflation and the output gap. Table 2 reports the corresponding estimates 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 official Fed statements,[13] and with conventional wisdom regarding the lag with which monetary policy impacts either variable. In either case, the results are qualitatively very similar to those reported in Table 1, with the same large, significant differences in the estimates of β and γ across sample periods in place.

To illustrate how well the model characterizes the behavior of the funds rate, Figure 1 presents the target rates estimates for each sub-period relative to the actual values of the funds rate. 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.[14]

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[13] See the quotation by Greenspan above.

[14] 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.

3.3. Post-1982

We also want to check whether the detected differences across samples may be driven by the special operating procedures that were effective from October 1979 through the summer of 1982 (i.e., the early segment of the Volcker period), and which involved the targeting of nonborrowed reserves[15] (as opposed to the Funds rate).[16] In order to do so we re-estimate our model for the period 1982:4-1996:4, with the results shown in Table 3. As it was the case for the full Volcker-Greenspan sample period, the estimates for β are in all cases significantly above one (with some point estimates being above two).[17] The only difference lies in the fact that γ is significantly above zero in three out of the four cases reported, which conflicts with the pure inflation targeting characterization that was suggested by our previous estimates.

Overall, our estimates point to what seems to be a robust feature of the data, namely, the existence of important differences across periods in the sensitivity of

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[15] 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).

[16] Bernanke and Mihov (1997) present evidence that over the 1979:10 - 1982 period nonborrowed 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. 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 an interest rate objective in expectation as defined by the reaction function.

[17] We also tried fitting the model just over the Greenspan period, and found that for most specifications the slope coefficient on expected inflation was not significantly above one. In our view, there was not sufficent variation in inflation over this period to identify the policy-response to inflation. Interestingly, however, the model estimated over the whole post-1979 sample appers to explain the Greenspan period fairly well (se Figure 1.)

interest rate policy to changes in expected inflation. Such differences are hardly innocuous, and are likely to have very different implications for macroeconomic stability. Specifically, during the pre-Volcker period the Fed tended to raise its target nominal rate by less than the rise in expected inflation (two thirds of that rise, approximately), thus implying a *decline* in the target real rate in response to anticipated inflationary pressures, a response that can hardly be seen as inflation-stabilizing.[18] By way of contrast, under the Volcker-Greenspan regime, target real rates have been substantially raised in the wake of an anticipated increase in inflation (roughly, on a two-for-one basis, according to 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 may have been ultimately responsible for the stability in inflation experienced by the US economy in recent years. The contrast between the implications of the two rules is discussed the next section in the context of a standard business cycle model.

4. Interest Rate Rules and Economic Fluctuations

In this section we analyze and discuss some of the macroeconomic implications of interest rate rules of the sort estimated above. We do so in the context of a familiar business cycle model with sticky prices. We first present the model's

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[18] 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 and after October 1979.

equilibrium conditions, and then analyze some of the properties associated with the estimated rules for the pre-Volcker and the Volcker-Greenspan eras. 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 systematic component of U.S. monetary policy may have been in itself a *source* of macroeconomic instability.[19]

4.1. A Business Cycle Model with Sticky Prices

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

$$\pi_t = \delta\ E[\pi_{t+1}|\Omega_t] + \lambda\ y_t \tag{4.1}$$

$$y_t = E[y_{t+1}|\Omega_t] - \frac{1}{\sigma}\ (r_t - E[\pi_{t+1}|\Omega_t]) \tag{4.2}$$

$$r_t^* = \beta\ E[\pi_{t+1}|\Omega_t] + \gamma\ y_t \tag{4.3}$$

$$r_t = \rho\ r_{t-1} + (1-\rho)\ r_t^* \tag{4.4}$$

Equation (4.1) describes the change in the aggregate price level as a function of expected future inflation and the deviation of (log) output from its steady

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

state (the latter is normalized to zero). Such an equation 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.[20] Equation (4.2) combines a standard Euler equation for consumption with a market clearing condition equating aggregate consumption and output.[21] It is often interpreted as an IS equation, determining current aggregate output as a function of the ex-ante real rate and expected future output. Equations (4.3) and (4.4) are the theoretical model's counterpart to (2.1) and (2.3). 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.

4.2. Equilibrium Dynamics

Define the vector of endogenous variables $\mathbf{x}_t = [\pi_t, y_t, r_{t-1}]'$. After using (4.3) to substitute for r_t^* in (4.4), and some rearranging, we can rewrite the equilibrium conditions (4.1)-(4.4) as a first-order difference equation:

$$E_t \, \mathbf{x}_{t+1} = A \, \mathbf{x}_t \tag{4.5}$$

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[20] 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. See Woodford (1996) for a formal derivation. 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).

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

where A is a matrix given by

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

As shown in Blanchard and Kahn (1980), the nature of the set of solutions to (4.5) hinges critically on the eigenvalues of A, and the fact that only one of the variables in $\mathbf{x}_t$ is predetermined (the lagged interest rate). To see this, let μ_1, μ_2, and μ_3 represent the eigenvalues of A and assume, without lost of generality, that $|\mu_1| \geq |\mu_2| \geq |\mu_3|$.

Let $A = QJQ^{-1}$, where J is the Jordan matrix associated with A, and Q is the corresponding matrix of eigenvectors. Define the vector of canonical variables $\mathbf{w}_t = [u_t, s_t]' = Q^{-1}\ \mathbf{x}_t$, where u_t and s_t are associated, respectively, with the unstable and stable eigenvalues. Let $Q = [Q_u, Q_s]$ be the corresponding partition of the matrix of eigenvectors. Thus, we can rewrite (4.5) as

$$E_t \begin{bmatrix} u_{t+1} \\ s_{t+1} \end{bmatrix} = \begin{bmatrix} J_u & 0 \\ 0 & J_s \end{bmatrix} \begin{bmatrix} u_t \\ s_t \end{bmatrix} \tag{4.6}$$

Ruling out explosive solutions requires that $u_t = 0$, for all t, implying that $\mathbf{x}_t = Q_s\ s_t$. But how is s_t determined?

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 Q_s is a (3×1) vector and, with appropriate normalization choice, $s_t = r_{t-1}$. Since r_{t-1} is predetermined, it follows that $s_{t+1} = E_t s_{t+1}$, (4.6) implying that

$s_t = \mu_3 \; s_{t-1}$, and hence, $\mathbf{x}_t = r_{-1} Q_s \; \mu_3^t$. In other words, the only possible non-explosive equilibrium is deterministic and involves a converging path of inflation, output, and the interest rate towards their steady state values.

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 s_t is two-dimensional and cannot be pinned down by uniquely by the lagged interest rate. Furthermore, for any *arbitrary* scalar martingale-difference sequence of sunspot innovations $\{\eta_t\}$ (i.e., $E_t \; \eta_{t+1} = 0$, all t) there exists a stationary stochastic processes for $\{s_t\}$ satisfying (4.6) of the form

$$s_t = J_s \; s_{t-1} + G \; \eta_t$$

where G is an arbitrary (2×1) vector satisfying by $[0, 0, 1] Q_s G \; = 0$.[22] It follows that

$$\mathbf{x}_t = \sum_{k=0}^{\infty} Q_s \; J_s^k \; G \; \eta_{t-k}$$

i.e., inflation, output, and the interest rate may display genuine stationary stochastic fluctuations around their steady state values, even in the absence of any shocks to fundamentals, and as a result of self-fulfilling revisions in expectations caused by innovations in the sunspot variable. Notice that such fluctuations, though stationary, are potentially very persistent, with the degree of persistence measured by the "highest" stable eigenvalue (i.e., μ_2).

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[22] That restriction on G guarantees that r_{t-1} is not affected by η_t.

4.3. Interest Rate Rules and Endogenous Fluctuations

Next we investigate the role of the interest rate rule as a possible source of such fluctuations. Our strategy consists in calibrating the simple model above and analyzing the properties of the dynamical system describing the corresponding equilibrium. Calibration of the model starts by assigning some benchmark values to parameters σ, δ, and λ (i.e., parameters other than those describing the policy rule) similar to the ones used by other authors in the literature. Given those 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 U.S. data.

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%. 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.[23]

In Table 4 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 fluctuation, given the baseline values for (σ, δ, λ) and alternative parameter configurations for γ–the output coefficient–and ρ–the interest smoothing parameter. We want to stress 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

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[23] 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).

validated or not by the response of the monetary authority and, thus, whether it is consistent or not with equilibrium.[24] Strictly speaking, that threshold value for β obtains exactly only when $\gamma = 0$, i.e., when there is no systematic response to output variations.[25] 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 also lead to sunspot fluctuations.[26] 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, and given our baseline values for the non-policy parameters, we compute the eigenvalues associated with two calibrations of the interest rate rule that are representative of the estimates obtained for the pre-Volcker and Volcker-Greenspan eras in our empirical work above. In either case, we restrict ourselves to the estimates based on a one-quarter ahead horizon for both inflation and output ($k = q = 1$) found in Table 1. The eigenvalues for each set of estimates are

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[24] We should stress that we are not considering some complciations 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.

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

[26] This is the case emphasized by Bernanke and Woodford (1997) in a very similar model.

reported in Table 5.

As one could anticipate from the results in Table 4, 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 such 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 2, which displays simulated time series for output, inflation and the nominal rate under the rule corresponding to the first row of Tables 1 and 5, 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 3 displays the impulse responses of some key macro 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, 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, and as seen in the bottom panel of Table 5, the estimated interest rate rule for the Volcker-Greenspan period generates two eigenvalues with moduli above one. As discussed above, that 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.[27] In other words, the monetary policy rule is not, *in itself*, a source of macroeconomic instability.

5. Conclusions

In this paper we have provided an empirical characterization of the systematic component of U.S. monetary policy in the postwar era. In order to do so, we estimated a simple forward looking interest rate rule.

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 thus 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

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[27] 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.

that result from self-fulfilling changes in expectations.

One important question our paper raises but does not answer is the following: Why is it that during the pre-1979 period the Fed 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 DeLong (1997), is that the Fed thought the natural rate of unemployment at this time was much lower than it really was (or equivalently, potential output was much higher.) There is considerable anecdotal evidence to support this view, 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.[28] 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 idea that expections 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.

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

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Table 1

Target Horizons: $k = 1$, $q = 1$

	$\widehat{\beta}$	$\widehat{\gamma}$	$\widehat{\rho}$	p
1960:1-1979:2				
GDP	0.80 (0.09)	0.44 (0.11)	0.75 (0.04)	0.16
Unemployment	0.73 (0.06)	0.78 (0.12)	0.62 (0.05)	0.23
1979:3-1996:4				
GDP	1.80 (0.19)	0.12 (0.13)	0.66 (0.04)	0.31
Unemployment	1.77 (0.17)	0.12 (0.24)	0.64 (0.03)	0.21
Structural Change				
GDP	<0.01	0.19	0.90	
Unemployment	<0.01	0.10	0.34	

Note: The set of instruments includes four lags of inflation, output gap, funds rate, spread, commodity price inflation, and money growth.

Table 2

Alternative Target Horizons

	$\widehat{\beta}$	$\widehat{\gamma}$	$\widehat{\rho}$	p
1960:1-1979:2				
$k = 4,\ q = 1$	0.80	0.52	0.76	0.84
	(0.09)	(0.12)	(0.04)	
$k = 4,\ q = 2$	0.84	0.53	0.77	0.84
	(0.10)	(0.12)	(0.04)	
1979:3-1996:4				
$k = 4,\ q = 1$	1.96	0.07	0.66	0.89
	(0.20)	(0.10)	(0.03)	
$k = 4,\ q = 2$	1.97	0.08	0.67	0.89
	(0.21)	(0.11)	(0.03)	
Structural Change				
$k = 4,\ q = 1$	<0.01	0.06	0.71	
$k = 4,\ q = 2$	<0.01	0.11	0.69	

Note: The output gap measure is detrended log GDP. The set of instruments includes four lags of inflation, output gap, funds rate, spread, commodity price inflation, and money growth.

Table 3

Volcker-Greenspan post-82

	$\hat{\beta}$	$\hat{\gamma}$	$\hat{\rho}$	p
GDP				
Horizon (1,1)	1.46	0.74	0.87	0.12
	(0.49)	(0.34)	(0.04)	
Horizon (4,1)	2.68	0.56	0.84	0.93
	(0.34)	(0.16)	(0.01)	
Unemployment				
Horizon (1,1)	1.64	0.93	0.84	0.27
	(0.42)	(0.42)	(0.04)	
Horizon (4,1)	2.39	0.93	0.84	0.94
	(0.41)	(0.34)	(0.02)	

Note: The sample period is 1982:4-1996:4. The set of instruments includes four lags of inflation, output gap, funds rate, spread, commodity price inflation, and money growth.

Table 4

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

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

Table 5

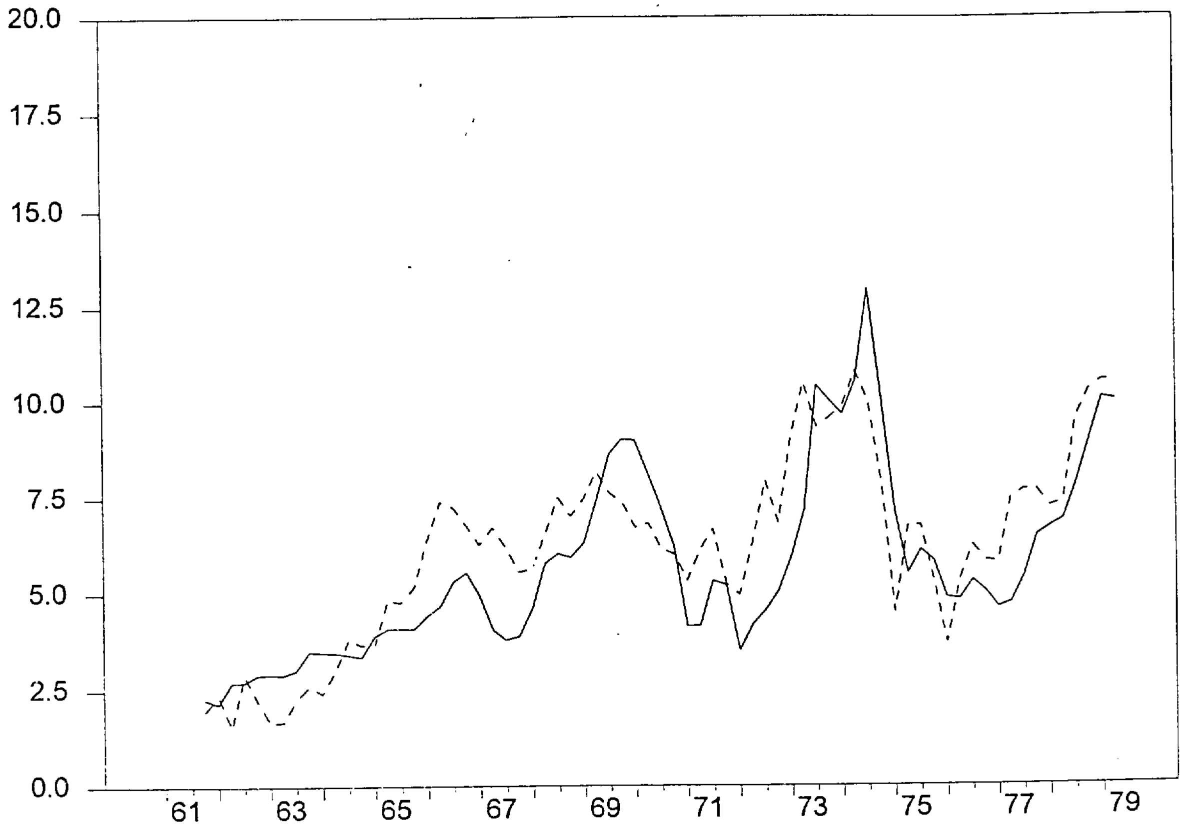
Eigenvalues for Calibrated Model

	$\|\mu_1\|$	$\|\mu_2\|$	$\|\mu_3\|$
1960:1-1979:2			
GDP	1.68	0.96	0.46
Unemployment	1.83	0.94	0.35
1979:3-1996:4			
GDP	1.24	1.24	0.43
Unemployment	1.23	1.23	0.42

Note: each row reports the three moduli of the eigenvalues of matrix A implied by the calibrated model, using the corresponding estimates of (β, γ, ρ) from Table 1.

Figure 1: Actual Rate vs. Estimated Target Rate

Pre-Volcker era



Volcker-Greenspan era

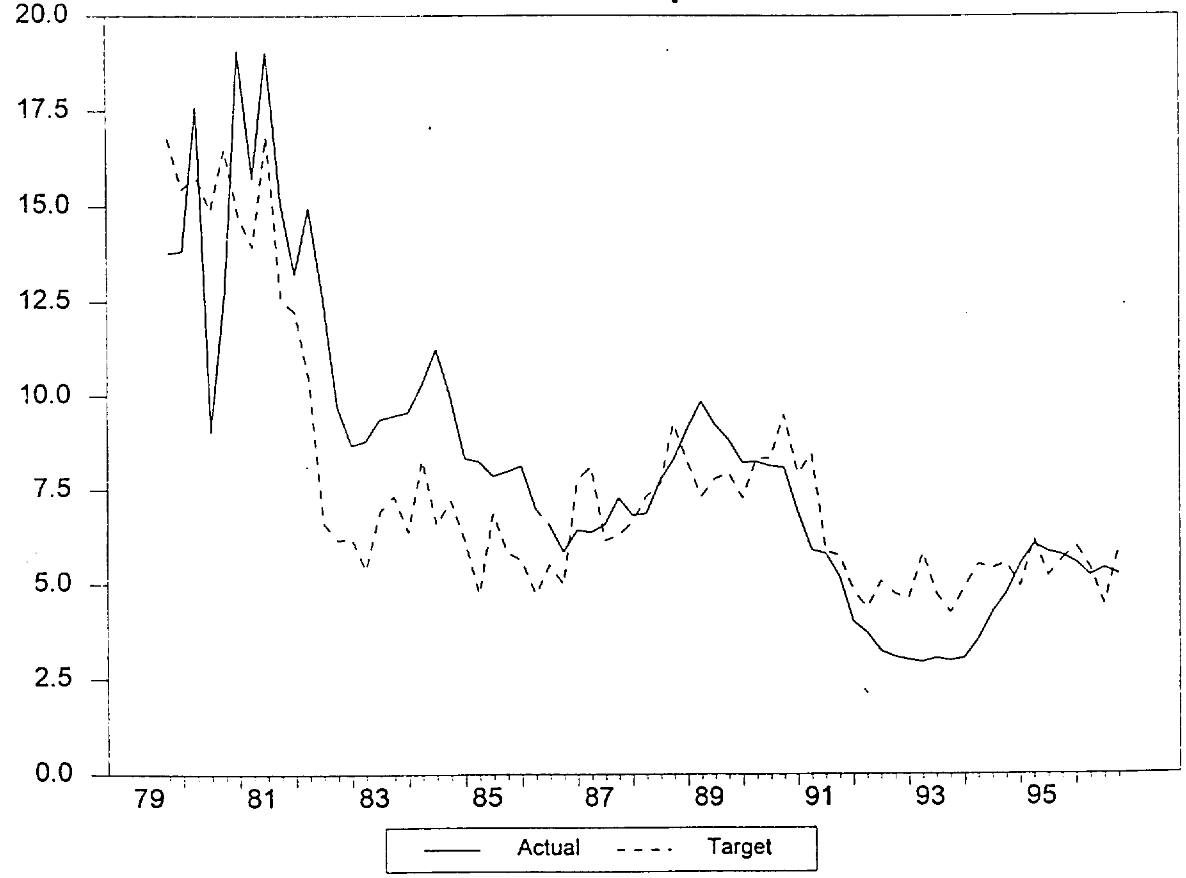
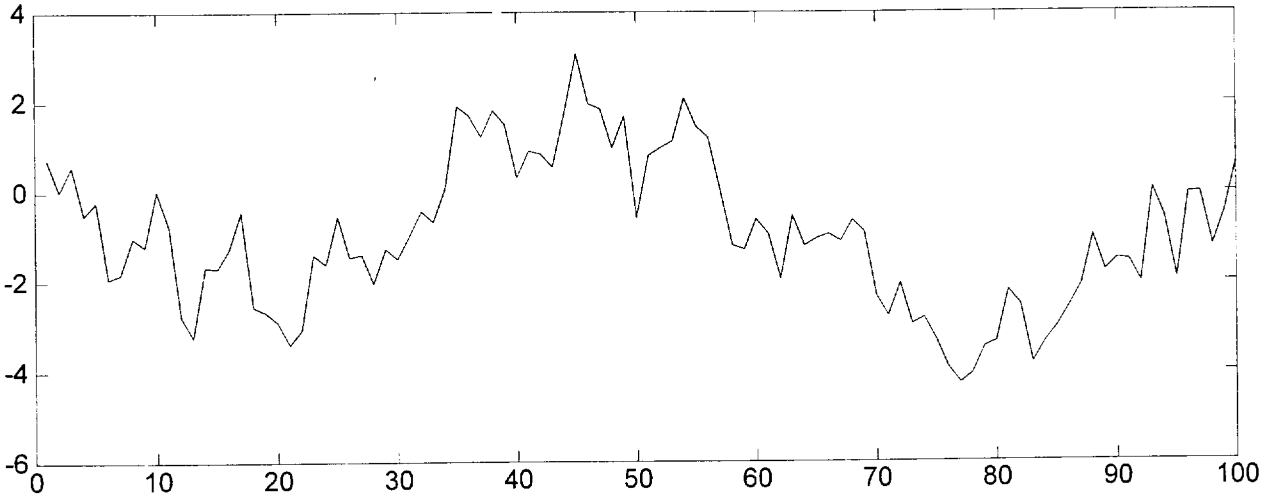
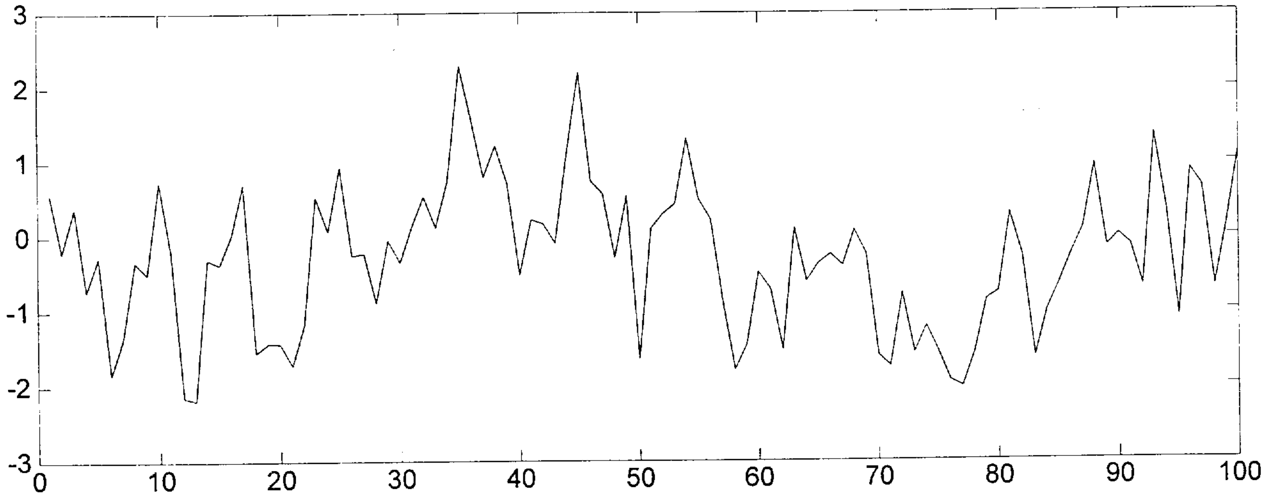


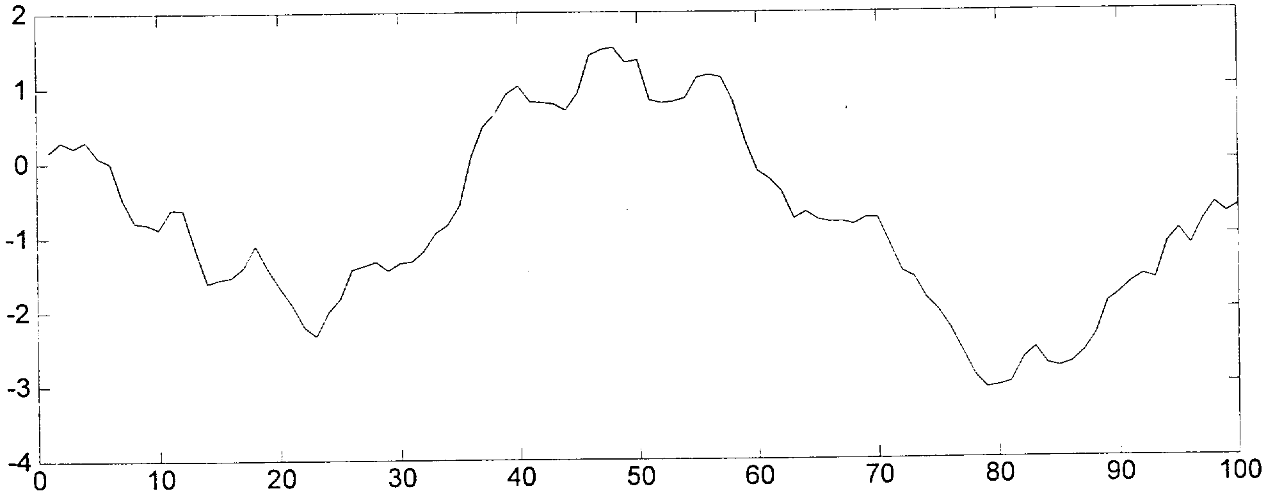
Figure 2: Simulated Sunspot Fluctuations under Pre-Volcker Rule



inflation



output gap



nominal rate

Figure 3: Impulse Responses to a Sunspot Shock