Controlling Inflation with an Interest Rate Instrument

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In this paper we examine the effectiveness in controlling long-run inflation of feedback rules for monetary policy that link changes in a short-term interest rate to an intermediate target for either nominal GDP or M2. We conclude that a rule aimed at controlling the growth rate of nominal GDP with an interest rate instrument could be an improvement over a purely discretionary policy. Our results suggest that the rule could provide better long-run control of inflation without increasing the volatility of real GDP or interest rates. Moreover, such a rule could assist policymakers even if it were used only as an important source of information to guide a discretionary approach.

In Congressional testimony, Chairman Greenspan and other Federal Reserve officials have made it clear that price stability is the long-run goal of U.S. monetary policy.[1] At the same time, reducing fluctuations in real economic activity and employment remains an important short-term goal of the System. However, the desire to mitigate short-term downturns inevitably raises the issue of whether this goal should take precedence over price stability at any particular point in time. At present, the Federal Open Market Committee (FOMC) resolves this issue on a case by case basis, using its discretion to set policy after analysis of a wide array of real and financial indicators covering the domestic and international economies.

Economic theory suggests that monetary policy tends to have an inflationary bias under such a discretionary system. This bias can be eliminated by the monetary authority pre-committing itself to a policy rule that would ensure price stability in the long run (Barro 1986). Even if the monetary authority is not willing to adhere rigidly to a rule, a discretionary approach could benefit from the information provided by a properly designed rule. For example, the instrument settings defined by the rule at any time could be regarded as the baseline policy alternative that would serve as the starting point for policy discussions. At its discretion, the FOMC could select a policy that was easier, tighter or about the same as that called for by the policy rule. Under such an approach, the rule could provide information that would help to guide short-run policy decisions toward those consistent with the long-run goal of price stability.

In this paper, we assess the effectiveness of so-called nominal feedback rules of the type suggested by Bennett McCallum (1988a, 1988b). These rules specify how a policy instrument (a variable that is under the direct control of the central bank) responds to deviations of an intermediate target variable from pre-established values. Earlier work (Judd and Motley 1991) suggests that a rule in which the monetary base is used as the instrument and nominal

*An earlier version of this paper (Judd and Motley 1992) will be published under the same title in a forthcoming issue of *Finance and Economics Discussion Series*, Board of Governors of the Federal Reserve System.

[1]See Greenspan (1989) and Parry (1990).

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GDP is used as the intermediate target could have produced price level stability with a high degree of certainty over the past 30 years.

Over many years, the Fed has shown a strong preference for conducting policy using an interest rate instrument, as opposed to a reserves or monetary base instrument. In the present paper, we examine rules that use an interest rate instrument in conjunction with nominal GDP as the intermediate target. In addition, since the mid-1980s, the Fed has used a broad monetary aggregate, M2, as its main intermediate target or indicator. Hence, we also assess the usefulness of a rule that combines an interest rate instrument with M2 as the intermediate target variable.

Evaluating the effects of policy rules in advance of actually using them is an inherently perilous task. First, the effects of a rule will depend on the structure of the economy, including several features—such as the degree of price flexibility and the way in which expectations are formed—that remain subjects of debate and disagreement among macroeconomists (Mankiw 1990). This lack of consensus about issues that crucially affect the working of the economy means that, in order to be credible, any proposed rule must be demonstrated to work well within more than one theoretical paradigm. Second, implementation of a rule could alter key behavioral parameters affecting price setting and expectations formation. This means that history may not be a good guide in evaluating rules that were not implemented in the past, and that the robustness of empirical results to alternative parameter values also must be examined.

In order to assess their effectiveness under alternative macroeconomic paradigms, we conduct simulations of two different macroeconomic models (a Keynesian model and an atheoretic vector autoregression or error correction system) that have significant followings among macroeconomists.[2] To assess the risks of adopting different rules, we examine the dynamic stability of these models under alternative versions of the rules. In addition, we use stochastic simulations to determine the range of outcomes for prices, real GDP and a short-term interest rate that we could expect if these rules were implemented and the economy experienced shocks similar in magnitude to those in the past. Finally, to test for robustness, we re-examine all of the results under plausible alternative values for key estimated parameters in the models.

[2]Our earlier paper (Judd and Motley 1991), in which the policy instrument was the monetary base, also examined the effects of a rule within the context of a very simple real business cycle (RBC) model. However, with an interest rate instrument, the price level cannot be determined in the context of that RBC model (see McCallum 1988b, pp. 61-66). Thus we did not use the RBC model in this paper.

Using these simulations we evaluate the effectiveness of the rules at controlling the price level. We also examine the effect of the rules on the volatility of real GDP and a short-term interest rate. Although we find that interest rate rules could have held long-run inflation below levels that were observed historically, they do not perform as well as base-oriented rules. However, there are reasons to believe that the base would be a less effective instrument in the future than it would have been in the past. Moreover, one simple form of the interest rate rule does appear to offer an improvement over a purely discretionary approach. Finally, we suggest a way to use a feedback rule with an interest rate instrument as an important source of information that could contribute to the effectiveness of a discretionary policy.

The remainder of the paper is organized as follows. Section I presents a brief overview of the theoretical advantages and disadvantages of alternative targets and instruments. Section II discusses the nominal feedback rules to be tested. In Section III, we present the empirical results. The conclusions we draw from this work are presented in Section IV.

I. Conceptual Issues

In this section, we discuss briefly the basic conceptual issues determining the effectiveness of alternative intermediate targets and instruments of monetary policy. To illustrate certain basic ideas, we introduce a generic form of the feedback rule that links the *instrument* variable with the *intermediate target* variable. This generic feedback rule may be written in the form:

$$\Delta I_t = \psi + \lambda[Z^*_{t-1} - Z_{t-1}].$$

The variable I represents the policy instrument, which is a variable under the direct control of the monetary authority. Z represents the intermediate target variable of policy. The rule specifies that the change in the policy instrument should be equal to the change desired in steady-state equilibrium, ψ, plus an adjustment term, $\lambda[Z^*_{t-1} - Z_{t-1}]$. This latter term describes the monetary authority's response to deviations between the actual level of the intermediate target variable (Z) and its desired level (Z^*). The strength of the monetary authority's response to such deviations is defined by λ. Thus, the rule permits policy to incorporate varying degrees of aggressiveness in pursuing the intermediate target.

The policy instrument, I, responds only to lagged, and hence *observed*, values of the intermediate target Z. Hence, the rule can be implemented without reference to any particular model. This is an advantage in view of the current disagreement about the "correct" model of the economy.

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Nominal feedback rules may gain wider appeal because it may be possible to agree about the effectiveness of a particular rule, while disagreeing about certain aspects of how the economy actually works.

Alternative Intermediate Targets

The appeal of nominal GDP as an intermediate target lies in the apparent simplicity of its relationship with the price level, which is the ultimate long-term goal variable of monetary policy (Hall 1983). As shown by the following identity, the price level (p) is equal to the difference between nominal GDP (x) and real GDP (y), where all variables are in logarithms:

$$p = x - y.$$

This identity means that there will be a predictable long-term relationship between nominal GDP and the price level as long as the level of steady state real GDP is predictable.

According to some economists, the level of real GDP has a long-run trend, called potential GDP, which is determined by slowly evolving long-run supply conditions in the economy, including trends in the labor force and productivity (Evans 1989). To the extent that this view is correct, it is straightforward to calculate the path of nominal GDP required to achieve long-run price stability.

However, other research suggests that real GDP does not follow a predictable long-run trend, and is stationary only in differences (King, Plosser, Stock and Watson 1991). If this were the case and nominal GDP were to grow at a constant rate under a rule, the price level would evolve as a random walk, and thus could drift over time. Unfortunately, statistical tests are not capable of distinguishing reliably between random walks and trend stationary processes with autoregressive roots close to unity (Rudebusch 1993). This uncertainty over the long-run behavior of real GDP means that there is corresponding uncertainty over how the price level would behave under a nominal GDP target.[3]

Another potential problem is that the lags from policy actions to nominal GDP are relatively long, and thus targeting nominal GDP might induce instrument instability. Shorter lags tend to exist between policy actions and monetary aggregates. Hence, using an aggregate as an intermediate target could reduce the likelihood of producing instrument instability compared to a nominal GDP target.

Since the velocity of M1 began to shift unpredictably in the early 1980s, M2 has been the main intermediate target used by the Fed and so is a prime candidate for use in a feedback rule. M2 also has been identified as a potential intermediate target because its velocity (in levels) has been stationary over the past three decades (Miller 1991, Hallman, Porter and Small 1991). Its short-run relationship with spending, however, has not been very reliable. These problems have intensified in recent years, with accumulating evidence of instability in M2 velocity in 1990–1992 (Judd and Trehan 1992, Furlong and Judd 1991). Nonetheless, it may be possible to exploit its long-run relationship with prices to achieve price stability.

For present purposes, the important implication of the preceding discussion is that the choice of an intermediate target variable cannot be determined from theory alone. This choice depends on empirical factors such as the time series properties of real GDP, the degree of flexibility of prices, and the predictability of the velocity of money. Clearly an empirical investigation is needed.

Alternative Instruments

Instruments of monetary policy fall into two basic categories: aggregates that are components of the Federal Reserve's balance sheet, such as the monetary base or the stock of bank reserves, and short-term interest rates, such as the federal funds rate. Either category qualifies as a potential instrument since either can be controlled precisely in the short run by the central bank and each is causally linked to output and prices.

The monetary base has the advantage that, in principle, it is the variable that determines the aggregate level of prices, and thus would appear to be a natural instrument to use in a rule designed to achieve price stability. However, it has a number of potential disadvantages. First, using the base as an instrument could cause interest rates to become excessively volatile, and thereby impair the efficiency of financial markets. Second, the base is made up mainly of currency in the hands of the public (currently, about 85 percent), and concern for efficiency in the payments system argues for supplying all the currency the public demands. This means that controlling the base requires operating on a small component of it (bank reserves). Hence, relatively small changes in the base might require

[3] In part because of this concern, a number of authors have argued that the Federal Reserve should target prices directly (Barro 1986, and Meltzer 1984). No matter what time series properties real GDP displays, direct price level targeting obviously could avoid long-term price-level drift. The major disadvantage of price level targeting is that in sticky price models, the feedback between changes in the instrument and the price level is very long (and, in fact, longer than for nominal GDP). Thus, attempts by monetary policy to achieve a predetermined path for prices are liable to involve instrument instability (i.e., explosive paths for the policy instrument) and undesirably sharp movements in real GDP. Our earlier empirical results (Judd and Motley 1991) confirm this conjecture.

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large proportional changes in reserves, which could disrupt the reserves market. Third, along with M1, the demand for the base has become relatively unstable in the 1980s compared with prior decades. The deregulation of deposit interest rates and increased foreign demand for U.S. currency apparently have induced permanent level shifts in the demand for the base, and possibly a change in its steady-state growth rate.

In Judd and Motley (1992, Appendix C) we examine the stability of the demand for base money and the issue of whether the need to supply currency on demand would seriously inhibit the use of the base as a policy instrument. We conclude that although these problems are legitimate reasons for concern whether a base rule would work well, they probably are not fatal. Nonetheless, it is worthwhile to explore the possibility of using a short-term interest rate as the instrument in the context of the feedback rule since the FOMC has shown a preference over the years for using the federal funds rate as its instrument.[4] This is our main purpose in this paper.

It is well-known that an interest rate would not be a satisfactory intermediate target for policy. The economy would be dynamically unstable in the long run (i.e., the price level would be indeterminate) if nominal interest rates were held steady at a particular level and not permitted to vary flexibly in response to shocks. However, this argument does not rule out its use as an *instrument*. If interest rate movements are linked to changes in a nominal variable (such as nominal GDP, a monetary aggregate, or the price level itself) through a rule, the price level may be determinate (McCallum 1981). Thus the question of whether an interest rate instrument would function effectively within a feedback rule cannot be answered by theory alone. Empirical work is required.

II. Nominal Feedback Rules

We examine two rules in which the interest rate is used as the instrument and one that uses the monetary base. We use the following symbols throughout: b = log of the monetary base, R = the three-month Treasury bill rate, $m2$ = log of the broad monetary aggregate, M2, x = log of nominal GDP, y^f = log of full-employment real GDP, and "*" denotes a value desired by the central bank.

Equation 1 employs nominal GDP as the intermediate target and the interest rate as the instrument.

$$(1)\quad \Delta R_t = -\lambda_1[x^*_{t-1} - x_{t-1}] + \lambda_2[x^*_{t-2} - x_{t-2}] = -\alpha[x^*_{t-1} - x_{t-1}] - \beta[\Delta x^*_{t-1} - \Delta x_{t-1}]$$

where $\alpha = (\lambda_1 - \lambda_2)$, $\beta = \lambda_2$.

Equation 2 is similar but uses M2 as the target.

$$(2)\quad \Delta R_t = -\alpha[x^*_{t-1} - \bar{V2}_{t-1} - m2_{t-1}] - \beta[\Delta x^*_{t-1} - \Delta\bar{V2}_{t-1} - \Delta m2_{t-1}]\ ,$$

where $\bar{V2}_t = \sum_{i=0}^{15}(x_{t-i} - m2_{t-i})/16$.

In order to provide a standard of comparison, we also examine a rule in which a base instrument is used to reach a nominal income target.[5]

$$(3)\quad \Delta b_t = [\Delta y^f_t + \Delta p^*_t] - \Delta\bar{VB}_t + \alpha[x^*_{t-1} - x_{t-1}] + \beta[\Delta x^*_{t-1} - \Delta x_{t-1}]\ ,$$

where $\Delta\bar{VB}_t = [(x_{t-1} - b_{t-1}) - (x_{t-17} - b_{t-17})]/16$.

The left hand sides of these equations represent the change in the policy instrument, either the annualized growth rate of the monetary base or the percentage point change in the short-term interest rate. Since in steady state the rate of interest is constant, the left hand sides of (1) and (2) are zero in equilibrium. Hence, the interest rate rules contain only a feedback component, which specifies how the interest rate is adjusted when the target variable (nominal GDP or M2) diverges from the path (in levels or growth rates) desired in the previous quarter. In (2), the target level of M2 (in logarithms) is defined as the target level of nominal income less the average level of M2 velocity over the past 16 quarters. The terms α and β define the proportions of a target "miss" (in levels and growth rates, respectively) to which the central bank chooses to respond in each quarter. In equilibrium, there are no misses and hence the interest rate is constant.

The monetary base rule is more complicated. The first

[4]Apparently, this preference is based in part on the view that this approach avoids imparting unnecessary volatility to financial markets that would arise if policy were conducted using a reserves or monetary base instrument.

[5]In our earlier paper (Judd and Motley 1991), we also tested the following two rules:

$$\Delta b_t = \left[\Delta y^f_t + \Delta p^*_t\right] - \Delta\bar{VB}_t + \alpha\left[p^*_{t-1} - p_{t-1}\right]$$

$$\Delta b_t = \left[\Delta y^f_t + \Delta p^*_t\right] - \Delta\bar{VB}_t + \alpha\left[(y^f_{t-1} - y_{t-1}) + (\Delta p^*_{t-1} - \Delta p_{t-1})\right].$$

The price level target produced instability in the Keynesian model, while the second rule, suggested by Taylor (1985), produced dynamic instability in the vector autoregression.

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term on the right-hand side of (3) represents the growth rate of nominal GDP that the central bank wishes to accommodate in the long-run, which is equal to the sum of the desired inflation rate (Δp^*) and the steady-state growth rate of real GDP (Δy^f). The second term, $\Delta \overline{VB}$, subtracts the growth rate of base velocity over the previous four years, and is designed to capture long-run trends in the relation of base growth to nominal GDP growth.[6] The third term specifies the feedback rule determining how growth in the base is adjusted when there is a target miss in the previous quarter. In steady state, this feedback term drops out, so that the rule simply states that $\Delta b_t = \Delta y_t^f + \Delta p_t^* - \Delta \overline{VB}_t$.

In all three rules, we use two lags on the levels of the intermediate target variables. As shown in (1), this specification is equivalent to including one lag on the level and one lag on the growth rate of the target variable (McCallum, 1988b). Thus the instrument is subject to both "proportional" (response to levels) and "derivative" (response to growth rates) feedback. The addition of derivative feedback can improve the performance of proportional feedback rules in some circumstances (Phillips 1954). In any event, we evaluate the performance of the rules under all three possible categories of control: proportional only ($\alpha > 0, \beta = 0$), derivative only ($\alpha = 0, \beta > 0$), and both proportional and derivative ($\alpha > 0, \beta > 0$).

III. Empirical Results

For each of the rules tested, we performed a number of dynamic simulations within the context of two types of model: a simple structural model based on Keynesian theory, and a theoretically agnostic vector autoregression or error correction model.

The models are described in detail in Appendix A. The Keynesian model embodies four equations, each representing a basic building block of this framework. First, there is an aggregate demand equation, relating growth in real GDP to growth in real M2 balances (or the monetary base). Second, there is a Phillips-curve equation, relating inflation to the GDP "gap" (i.e., the difference between real GDP and an estimate of its full employment level), and a distributed lag of past inflation. This latter variable reflects the basic Keynesian view that prices are "sticky," and means that there are long lags from policy actions to price changes. Third, full-employment real GDP (in levels) is assumed to have a deterministic trend. Thus the supply of real GDP in levels is unaffected by business cycle developments. Finally, the model includes an equation defining the demand for (real) money (or the monetary base) as a function of real GDP, and the nominal interest rate.

To simulate this model with a base instrument, this last equation is replaced by the equation describing the policy rule (3). In simulations with an interest rate instrument, (1) and (2), the policy rule determines the interest rate, which feeds into the M2 or base demand equation to determine the monetary aggregate. Under both instruments, the simulation model includes the aggregate demand and supply equations and the Phillips curve to determine y, y^f and p.

In addition to the Keynesian model, we also use either a vector autoregression (VAR) or a vector error correction (VECM) framework. To simulate the effects of a rule with a base instrument, we use a four-variable VAR system, including real GDP, the GDP deflator, the monetary base, and the three-month Treasury bill rate. In these simulations, the estimated equation for the base is replaced by the policy rule (3). For the interest rate rules, we use a somewhat different system of equations. Since the second interest rate rule (2) involves M2 as the intermediate target, we replace the base with M2 in the above list of variables. We use this same system to simulate the effects of (1), which uses nominal GDP as the intermediate target. In simulating the interest rate rules, the estimated interest rate equation is replaced by the appropriate policy rule.

In estimating these systems, we used standard statistical techniques as described in Appendix A to test for stationarity, cointegration, and lag length. In the system that includes M2, we found one cointegrating relationship, which we interpret as an M2 demand function. This cointegrating vector was imposed in estimating the resulting VECM. No cointegrating vector was found in the system that includes the monetary base, and hence this system was estimated as a VAR.

The simulation results fall into three categories. First, we examine the dynamic stability of each macroeconomic model when the rules are used to define monetary policy. For a policy rule to be considered, it must produce a model that has sensible steady state properties. In the long run, a feedback rule will make the price level follow the desired path, as long as it does not make the economy dynamically unstable and induce explosive paths for the endogenous variables. Given the uncertainty about the true structure of the economy, a rule must produce dynamic stability in both types of models examined, and with a range of alternative values of α and β, in order to be considered reliable. We conduct numerous simulations to see if the rules meet this test.

Second, we conduct repeated stochastic counterfactual simulations of the alternative models and rules over the

[6] The 16-quarter average was designed to be long enough to avoid dependence on cyclical conditions. As a consequence, the term can take account of possible changes in velocity resulting from regulatory and technological sources.

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1960–1989 sample period to see how the principal macroeconomic variables might have evolved if the rules had been followed. In these simulations, we assume that the shocks in each equation have the same variance as the estimation errors. This procedure allows us to construct probability distributions of alternative outcomes for each rule and each model, and to calculate (95 percent) confidence intervals for long-run inflation rates as well as for short-run real GDP growth rates and for interest rate changes. This enables us to compare different rules in terms of the full range of alternative outcomes that each might produce. To compare the simulated results under the rules with the results of the policies actually pursued, we report the means and 95 percent confidence bands of the actual data over 1960–1989.

Third, we tested the robustness of these results by repeating many of the above simulations under alternative values of key parameters in our estimated models.

Dynamic Stability

The results of our analysis of the dynamic stability of the models under the various rules are shown in Table 1. To detect whether a particular combination of model, rule, and pair of α and β was dynamically stable, we computed a nonstochastic simulation covering 300 quarters. The size of the simulation's last cycle for the price level (peak-to-trough change) was divided by the size of its first cycle to form a ratio that we call s. If s is greater than 1.0, the simulation is unstable since the swings in the endogenous variable become larger as time passes, while a value of s less than 1.0 shows dynamic stability.[7] For each combination of model and rule, we performed a grid search over various combinations of α (to measure proportional control) and β (to measure derivative control). The grid extended from $\alpha = \beta = 0.0$ to $\alpha = 0.8$ and $\beta = 1.1$ (in units of 0.1 for both α and β). Excluding the combination in which $\alpha = \beta = 0.0$, which represents the no-rule case, each grid search generated 107 values of s. Although the exact specification of these searches is somewhat arbitrary, they do appear to present an accurate picture of the stability properties being investigated.

Table 1 provides a count of stable simulations for each rule under each model. As shown, the nominal GDP/base rule is dynamically stable in every simulation for both models. Thus the conclusion that an economy guided by a nominal GDP/base rule would have desirable steady state properties is quite robust across models and choices of α and β. In fact, in the case of a base instrument, the simple approach of proportional control (only) would seem to

[7]Nearly all of the simulations we observed exhibited cycles. However, the method used for detecting dynamic instability also works for simulations that do not exhibit cycles.

Table 1

Dynamically Stable Simulations by Type of Control

Rule Intermediate Target/Instrument	Proportional Only (10 trials)	Proportional and Derivative (89 trials)	Derivative Only (8 trials)	Total (107 trials)
Nominal GDP/Interest Rate				
Keynesian Model	6	68	7	81
VECM	1	13	7	21
M2/Interest Rate				
Keynesian Model	8	82	8	98
VECM	0	11	8	19
Nominal GDP/Monetary Base				
Keynesian Model	10	89	8	107
VAR	10	89	8	107

Note: The number of trials is the total number of pairs of α and β for each combination of rule and model.

Proportional Only: $\alpha > 0; \beta = 0$
Proportional and Derivative: $\alpha > 0; \beta > 0$
Derivative Only: $\alpha = 0; \beta > 0$

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make sense. In any event, the risk of inducing unstable cycles by using this rule appears to be small.

The same cannot be said for the interest rate instrument, using either nominal GDP or M2 as the intermediate target. Under the vector error correction model, the rule produces only 21 stable cases out of 107 trials when nominal GDP is the intermediate target, and only 19 stable cases when M2 is used. The results are considerably better in the Keynesian model (81 and 98 stable trials, respectively, for nominal GDP and M2 targets). However, the important characteristic of robustness across alternative models is lacking when the full range of combinations of proportional and derivative control is considered.

It is not entirely surprising that there is a tendency for the models to produce more cases of dynamic instability when an interest rate instrument is used than when the base is used. As noted above, economic theory predicts that the price level would be determinate in the long run and the economy dynamically stable if the monetary authority were to peg the base, but that the price level would be indeterminate and the economy dynamically unstable if the authority were to peg a nominal interest rate at a constant level. Although the feedback rules attempt to avoid this problem by tying interest rate changes to intermediate targets for nominal variables, the underlying tendency toward instability shows through in our results.

However, in the case of an interest rate rule that exerts derivative control only—so that policy responds only to the growth rates, and not the levels, of nominal GDP and M2—there does not appear to be a problem with instability. As Table 1 shows, the model is dynamically stable in all 8 trials when the intermediate target is M2, and in almost all trials (7 out of 8) when nominal GDP is the target.

Counterfactual Simulations

In this section we present the results of simulations that attempt to assess how the macroeconomy might have evolved over the past three decades if the various feedback rules had been in use. In these "counterfactual experiments," the targeted values of the intermediate target variables were set under the assumption that the Fed's goal was to hold the price level constant over 1960–1989. We chose values for α and β that produced stable simulations across the two models. For each combination of rule and model, we calculated 500 stochastic simulations.[8] The random shocks in each equation were drawn from probability distributions that had the same mean and variance as the estimation error terms. Each set of 500 simulations is called an experiment.

In presenting the results of these experiments, we focus on two measures of economic performance that should reflect the concerns of policymakers—the price level and the short-run growth rate of real GDP. Ideally, a policy rule should deliver price stability without causing unacceptable fluctuations in real GDP growth. To address possible concerns about the short-run variability of the interest rate under the rules, we also examine quarter to quarter changes in the interest rate instrument.

We measure the price level performance of each rule in terms of the average inflation rate that it produced over the 30-year simulation period. The volatility of real GDP is measured in terms of the four-quarter growth rate of real GDP. For each experiment, we calculated 95 percent confidence intervals for both of these variables. In the case of the simulations using the interest rate instrument, we also calculated 95 percent confidence intervals for the quarterly changes in the interest rate.

Table 2 shows the performance of the various rules in stabilizing the price level.[9] Using the monetary base as the instrument, adoption of the nominal-GDP feedback rule could have stabilized prices in the long run within narrow limits. For example, under the base rule with both proportional and derivative control ($\alpha = 0.25$ and $\beta = 0.50$), average inflation (with 95 percent probability) would have been between −0.4 and +0.3 percent in the Keynesian model and between −0.8 and +0.7 percent in the VAR. Under the policies actually followed during this period, average inflation was 5.4 percent.

The rules in which the interest rate is used as the instrument also are able to produce confidence bands that generally are centered near an average inflation rate of zero. However, these bands are wider than when the monetary base is used as the instrument. For example, under the interest rate instrument (with either proportional control alone or both derivative and proportional control), the width of the confidence bands ranges from 1.1 to 4.2 percentage points compared with band widths of 0.7 to 1.5 percentage points when the base is the instrument. Thus although both instruments produce confidence bands for average inflation that are centered on zero, use of the base as the policy instrument reduces price level uncertainty more than use of the interest rate.

[8]There are nine alternative rules (i.e., three combinations of intermediate targets and instruments, and three combinations of α and β) and two models. Thus eighteen sets of 500 stochastic simulations were computed.

[9]The average inflation results in Table 2 are not qualitatively changed if alternative horizons, such as five, ten or twenty years, are used for the stochastic simulations.

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Table 2

Simulated Average Annual Inflation Rate 1960–1989

Rule	95% Confidence Limit		
Intermediate Target/Instrument	**Proportional Only**	**Proportional and Derivative**	**Derivative Only**
Nominal GDP/Interest Rate	(α = 0.75, β = 0.00)	(α = 0.25, β = 0.50)	(α = 0.00, β = 0.50)
Keynesian Model	−0.6% to 0.5%	−1.3% to 0.9%	−2.3% to 4.9%
VECM	Explosive	−1.0% to 2.5%	−0.3% to 3.1%
M2/Interest Rate	(α = 0.75, β = 0.00)	(α = 0.60, β = 0.25)	(α = 0.00, β = 0.50)
Keynesian Model	−0.8% to 1.0%	−0.9% to 1.0%	−1.5% to 3.2%
VECM	Explosive	−1.2% to 3.0%	−0.2% to 3.5%
Nominal GDP/Monetary Base	(α = 0.50, β = 0.00)	(α = 0.25, β = 0.50)	(α = 0.00, β = 0.50)
Keynesian Model	−0.4% to 0.3%	−0.4% to 0.3%	−0.2% to 0.7%
VAR	−0.8% to 0.7%	−0.8% to 0.7%	−0.5% to 1.0%
Actual Data:		5.4%	

The confidence bands on average inflation are considerably wider under the interest rate rules if policy exerts only derivative control (see the right-hand column of Table 2). When policy attempts to control only the *growth rate* of the intermediate target, misses in the level in effect are "forgiven" each quarter. Not surprisingly, the widths of the resulting confidence bands on long-run inflation increase to between 3.4 and 7.2 percentage points. However, it is important to note that even at the top ends of these confidence bands, average inflation is below the actual inflation rate over 1960–1989.

Finally, the results suggest that there is little to distinguish the nominal GDP target from the M2 target under an interest rate instrument. However, our use of a sample period that ends in 1989 abstracts from the widely discussed problems with instability in the demand for M2 that have occurred in 1990–1992 (Furlong and Judd 1991, Judd and Trehan 1992). Since 1989, the velocity of M2 has been roughly constant, whereas historical relationships suggest that it should have declined rather sharply in response to declining nominal interest rates. This apparent shift in M2 demand raises concerns that the future performance of M2 as an intermediate target may be worse than it was in the past.

Table 3 shows the effects of the rules on the volatility of real GDP. For each model, it reports 95 percent confidence intervals for four-quarter growth rates of real GDP under the alternative rules.[10] The table compares the simulation results with the distribution of the actual historical data, which is a measure of the volatility of real GDP during the sample period under the discretionary policies actually followed by the Federal Reserve.

In nearly every case, the confidence bands are wider under the rules that use some proportional control (either alone or in combination with derivative control) than they were in the actual sample period, though in some cases the differences are small. For example, in the Keynesian model, use of the nominal GDP/base rule with both proportional and derivative control is estimated (with 95 percent confidence) to yield four-quarter real GDP growth rates of between −4.0 and +10.3 percent, which is wider than the −1.9 to +7.9 percent band in the historical data. In the VAR, the corresponding confidence interval is +0.4 to +9.3 percent, which has about the same width as the historical measure.

Table 3 suggests that use of an interest rate instrument, with at least some proportional control, would lead to larger fluctuations in real GDP growth than a base instrument. The confidence bands are substantially wider under rules that use an interest rate instrument than with a base

[10] We also looked at the volatility of the two-quarter and eight-quarter growth rates of real GDP. The conclusions were qualitatively the same as for the four-quarter growth measures.

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Table 3

Simulated Four-Quarter Real GDP Growth Rates

Rule	95% Confidence Limit		
Intermediate Target/Instrument	Proportional Only	Proportional and Derivative	Derivative Only
Nominal GDP/Interest Rate	(α = 0.75, β = 0.00)	(α = 0.25, β = 0.50)	(α = 0.00, β = 0.50)
Keynesian Model	−16.7% to 20.6%	−6.3% to 19.7%	−1.3% to 8.2%
VECM	Explosive	−11.7% to 19.8%	−0.6% to 10.2%
M2/Interest Rate	(α = 0.75, β = 0.00)	(α = 0.60, β = 0.25)	(α = 0.00, β = 0.50)
Keynesian Model	−7.2% to 13.6%	−4.7% to 10.6%	−1.6% to 8.3%
VECM	Explosive	−16.4% to 15.3%	0.8% to 10.0%
Nominal GDP/Monetary Base	(α = 0.50, β = 0.00)	(α = 0.25, β = 0.50)	(α = 0.00, β = 0.50)
Keynesian Model	−3.4% to 10.0%	−4.0% to 10.3%	−3.5% to 10.2%
VAR	−0.4% to 9.9%	0.4% to 9.3%	0.6% to 9.0%
Actual Data:		−1.9% to 7.9%	

instrument, especially in the VAR and VECM models. There appears to be a slight tendency for the confidence bands to be narrower under an M2 rule than a nominal GDP rule, but the difference is small.

However, *if only derivative control is exerted*, the width of the confidence bands on real GDP growth is noticeably narrower than when there also is a significant element of proportional control (see the right hand column of Table 3). In most cases, derivative control leaves the volatility of GDP at about the same level as it was historically. This is true whether an interest rate or a monetary base instrument is used.

In Table 4, we present evidence on the quarter-to-quarter volatility of the short-term interest rate that might result from following the two rules that use the interest rate as the instrument. When at least some proportional control is used, the rules result in an increase in short-run interest rate volatility compared with that experienced under the discretionary policy pursued in our sample period. Thus the width of the 95 percent confidence intervals varies from 5.2 to 16.9 percentage points under the rules, compared with a width of 4.0 percentage points in the actual data. However, use of derivative control only is estimated to reduce interest rate volatility compared with history. As shown in the right-hand column, the confidence bands range in width from 1.3 to 2.4 percentage points compared with the 4 point width in the actual data.

In summarizing the results in Tables 2, 3, and 4, it is useful to compare the simulations under an interest rate instrument both with those under a base instrument and with the historical record. Compared to the base-instrument results, we conclude:

1. Use of the interest rate permits much more long-run drift in the price level than use of the base.
2. An interest rate instrument also results in more volatility of real GDP, except in the case of derivative control only, when the interest rate instrument leads to less volatility.

Comparing the results under an interest rate instrument with historical experience, we can make the following generalizations:

1. If at least some proportional control is used, the interest rate rule would hold inflation well below its historical average, but would result in greater volatility in real GDP and interest rates than experienced in the past.
2. If derivative control only is used, then the interest rate rules would hold inflation somewhat below historical experience, maintain real GDP volatility at about its historical level, and result in less interest rate volatility than actually occurred in the past.

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Table 4

Simulated Quarter-to-Quarter Changes in the Short-Term Interest Rate
(percentage points)

Rule	95% Confidence Limit		
Intermediate Target/Instrument	Proportional Only	Proportional and Derivative	Derivative Only
Nominal GDP/Interest Rate	($\alpha = 0.75, \beta = 0.00$)	($\alpha = 0.25, \beta = 0.50$)	($\alpha = 0.00, \beta = 0.50$)
Keynesian Model	−8.3% to 8.6%	−3.7% to 3.8%	−1.1% to 1.3%
VECM	Explosive	−2.5% to 2.7%	−0.9% to 1.1%
M2/Interest Rate	($\alpha = 0.75, \beta = 0.00$)	($\alpha = 0.60, \beta = 0.25$)	($\alpha = 0.00, \beta = 0.50$)
Keynesian Model	−5.7% to 6.0%	−3.0% to 3.0%	−0.8% to 0.9%
VECM	Explosive	−3.5% to 3.7%	−0.6% to 0.7%
Actual Data:		−2.0% to 2.0%	

Robustness

One problem with attempting to evaluate empirically the likely effects of monetary policy rules that were not actually followed during the period for which data are available is that the estimated behavioral parameters of models might have been different if the rule had actually been used (Lucas 1973). In a crude attempt to deal with this issue, we have recalculated many of the simulations discussed above under alternative assumptions about key coefficients in our estimated models. We ran these simulations under the assumption that selected coefficients varied (one at a time) from their estimated levels by plus and minus two standard deviations. The results of these alternative simulations are shown in Appendix B.

The coefficients that were varied in these tests included the following:

1. In the Keynesian model, we altered the slope of the Phillips curve, the elasticities of real GDP with respect to both real M2 and the real base in the aggregate demand equations, and the interest elasticities of the demand for both M2 and the base. In addition, we varied the length of the lags on past inflation in the Phillips curve, restricted the sum of these coefficients on past inflation to unity, and introduced a unit root in potential GDP.

2. In the VECM, we varied the interest rate, GDP and price elasticities of M2 in the cointegrating vector that appears in the M2 and price equations.

There are too many results in Appendix B to review in detail. However, several general points stand out. First, the results for average inflation are quite robust for all of the rules within all of the models. When the monetary base is the instrument, the results for real GDP growth also are robust, although somewhat less so than for inflation.

As shown in Tables B.2 and B.4, the width of the confidence bands for four-quarter real GDP growth is relatively sensitive to coefficient variations when the interest rate is used as the instrument and the rule involves some proportional control. In a few cases the bands become somewhat narrower, but in many more they become considerably wider. On the other hand, interest rate volatility is relatively less sensitive to the changes in the models' coefficients. However, as shown in Tables B.3 and B.5, when the interest rate rule involves derivative control only, the simulation results are highly robust.

One issue of special concern is the restriction in the Phillips curve that the coefficients on lagged inflation sum to unity (point 2 in Tables B.1, B.2, and B.3). This restriction ensures that monetary policy is neutral with respect to real GDP in the long run (i.e., it makes the Phillips curve "vertical" in the long run), and is a central feature of the theory underlying the Phillips curve. Although the restriction is rejected by the data in our sample (see the F test under equation A.2′ in the Appendix), we imposed it in our sensitivity analysis because of its theoretical importance. In most cases, the imposition of this restriction leads to dynamic instability.

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IV. CONCLUSIONS

In this paper, we have examined the effectiveness of nominal feedback rules that link short-run monetary policy actions to an intermediate target with the ultimate goal of controlling inflation in the long-run. Two subsidiary goals are that the rules not induce unacceptably large variations in real GDP or in interest rates. Given uncertainties about the structure of the economy, these rules are designed to be model-free in the sense that the monetary authority does not need to rely on a specific model of the economy in order to implement them. In addition, the rules are operational in that they define specific movements in an instrument that can be controlled precisely by the central bank.

We have focused mainly on rules that use a short-term interest rate as the policy instrument, and either nominal GDP or M2 as the intermediate target. As a standard of comparison, we also have looked at a rule in which the monetary base is the instrument and nominal GDP is the intermediate target. This rule has been shown to have desirable properties in earlier research. In addition, we compare the results from the rules with actual experience over the past three decades.

Our empirical results suggest that all of the feedback rules examined, so long as they do not produce explosive paths, would be highly likely to hold inflation below the average rate experienced in the U.S. over 1960–1989. When comparing rules with alternative instruments, the interest rate rule does not measure up to rules with the monetary base as the instrument and nominal GDP as the intermediate target. The latter rule provides much tighter control of the price level and induces somewhat less volatility in real GDP than rules using an interest rate as the instrument. Moreover, rules using the base as the instrument are consistent with dynamic stability in the economy under a wide range of assumptions, whereas the same cannot be said for rules with interest rate instruments. In a number of cases, the latter rules induced explosive paths in the economies simulated.

Despite the strong results obtained for rules with a base instrument, there are reasons to be concerned that their performance in the future would not measure up to the results obtained in our counterfactual simulations covering the past three decades. One important consideration is that the increase in foreign demand for U.S. currency in recent years may have made the overall demand function less stable than in the past.

So, what conclusions can be reached about the effectiveness of rules defined in terms of an interest rate instrument? First, within such rules, nominal GDP and M2 were found over our 1960–1989 sample period to function about equally well as intermediate targets. Given this result, and the evidence that the relationship between M2 and spending may have broken down during 1990–1992, rules defined in terms of nominal GDP would appear to be less risky.

Second, based upon our simulations, interest rate rules that involve some proportional control of nominal GDP (or M2) do not appear to be viable alternatives for monetary policy. We found a large number of cases in which these rules produced explosive paths for the simulated economy. Thus use of such a rule in the real world, where we do not know with any precision the structure and size of parameters of the pertinent behavioral relationships, would run a significant risk of inducing dynamic instability.

However, feedback rules with an interest rate instrument that focus on the growth rate, rather than the level, of nominal GDP (or M2) lead to dynamic stability in the various models. Naturally, such rules automatically accommodate past misses of the level of the intermediate target, and thus allow the possibility that the price level may drift over time. Such drift would occur only when there were a prolonged series of positive or negative shocks. However, it should be noted that even after allowing for such drift, the worst case simulation that we obtained still held the simulated average inflation rate over 1960–1989 below the historical average. Moreover, such an approach is estimated with a very high probability to involve about the same level of volatility in real GDP and a reduction in interest rate volatility compared with historical experience.

This conclusion suggests that, although a rule that aimed at controlling the growth rate of nominal GDP with an interest rate instrument is far from ideal, it might be an improvement over a purely discretionary interest rate policy. It would seem to offer the likelihood of lower long-run inflation without increasing the volatility of real GDP or interest rates. A simple version of such a rule can be written[11]

$$\Delta R_t = -0.50[\Delta x^*_{t-1} - \Delta x_{t-1}].$$

Such a rule could make a contribution to policy, even if it were used only to modify the Fed's traditional discretionary approach. When using an interest rate instrument within the context of a purely discretionary policy, it is natural for the policymaker to evaluate alternative policy actions relative to a status quo policy of leaving the interest rate (currently the federal funds rate) unchanged. As a

[11]As noted above, Δx refers to a change in the log of nominal GDP, while ΔR refers to a change in the interest rate expressed as a percent. Thus when nominal GDP growth deviates from its target by 1 percent (4 percent annual rate), the rule calls for a change in the interest rate of .005, or 50 basis points.

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result, the debate tends to focus on a decision about whether the funds rate should be raised or lowered from its recent level. This approach may be misleading, since a policy of leaving the funds rate unchanged does not necessarily imply that the future thrust of policy relative to key macroeconomic variables will remain unchanged.

However, the instrument setting given by the feedback rule at any point in time *does* provide a sensible way to define no change in monetary policy, since it represents a consistent policy regime, incorporating the long-run goal, the intermediate-run target and the short-run instrument. A debate that focused upon whether policy should ease, tighten, or remain the same *relative to what the feedback rule calls for*, would seem to be more informed than one that focused upon whether the short-term interest rate should be changed from recent levels. Occasional adjustments to the nominal GDP target could be used to offset drift in the price level that may arise from exercising derivative control (only) of nominal GDP.[12]

The approach outlined above could be considered as one possible step to improve a purely discretionary interest rate policy. In effect, the rule would be used to provide policymakers with information that could help them make short-run discretionary decisions without losing sight of the long-run goal of controlling inflation.

[12]If, for example, the level of prices were to drift significantly upward or downward despite following the rule, an offsetting adjustment could be made to the path of the nominal GDP target. Of course, the central bank would have to guard against the temptation to make frequent adjustments to the target path, since this could undermine the value of the feedback rule. One way to do this would be to define in advance the amount of drift in the price level that would be tolerated before a level adjustment would be made to the nominal GDP target.

Appendix A
Macroeconomic Models

We employed two alternative sets of assumptions about the structure of the economy: a Keynesian model and a vector autoregression (VAR) or vector error correction model (VECM). As will become apparent, the models are not attempts to describe the structure of the economy as precisely as possible. Rather, the Keynesian model incorporates the fundamental features of this macroeconomic paradigm. The VAR/VECM system is an atheoretic model that captures the statistical relations among various macroeconomic time series. These models are meant to illustrate the basic nature of the responses of the economy to the implementation of the monetary policy rules tested.

All of the equations below are estimated over 1960.Q1 to 1989.Q4. The variables in the regressions below are defined as follows:

b = log of monetary base (adjusted for reserve requirement changes)
cc = 1 in 1980.Q2, and 0 elsewhere
g = log of government purchases
$m2$ = log of M2
mm = 1 in 1983.Q1 and 0 elsewhere
p = log of GDP deflator
R = 3-month treasury bill rate
T = time trend
x = log of nominal GDP
y^f = log of real GDP trend (see equation A.3)
y = log of real GDP

Keynesian Model

The Keynesian, or "sticky price" model, consists of four equations. First, the real aggregate demand equation embodies the direct effects of monetary and fiscal policy on macroeconomic activity. In one version, it specifies the growth rate of real GDP as a function of current and lagged growth rates of the real monetary base, real government spending, and its own lagged values:

$$(A.1)\ \Delta y_t = \underset{(4.45)}{0.0045} + \underset{(2.06)}{0.17}\Delta y_{t-1} + \underset{(4.41)}{0.47}(\Delta b_{t-1} - \Delta p_{t-1}) + \underset{(2.52)}{0.016}\Delta g_t - \underset{(-2.52)}{0.016}\Delta g_{t-1}$$

$\bar{R}^2$ = 0.21
SEE = 0.0083
Q = 21.34
$D.F.$ = 116

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An alternative version uses M2 as the monetary policy variable:

(A.1′)
$$\Delta y_t = \underset{(3.18)}{0.0033} + \underset{(1.84)}{0.15\Delta y_{t-1}} + \underset{(5.09)}{0.41(\Delta m2_{t-1} - \Delta p_{t-1})} + \underset{(2.36)}{0.014\Delta g_t} - \underset{(-2.36)}{0.014\Delta g_{t-1}}$$

$\bar{R}^2 = 0.25$
$SEE = 0.081$
$Q = 27.26$
$D.F. = 116$

The supply side of the Keynesian model is a simplified Phillips curve, which embodies the essential "sticky price" characteristic of the paradigm. It specifies that the current inflation rate depends on past inflation and the gap between actual and full-employment real GDP ($y - y^f$). Theory suggests that the coefficients on lagged inflation should be constrained to sum to 1, thus ensuring that, in steady state, real GDP will be equal to its full-employment level, and inflation will be constant. However, the data over the sample period used reject this restriction at the 3.3 percent marginal significance level. Our basic model does not incorporate this restriction, but we also show results in which it is imposed (equation A.2′).

(A.2)
$$\Delta p_t = \underset{(1.89)}{0.0014} + \underset{(2.78)}{0.022(y_t - y_t^f)} + \underset{(3.02)}{0.28\Delta p_{t-1}} + \underset{(3.20)}{0.30\Delta p_{t-2}} + \underset{(2.20)}{0.25\Delta p_{t-3}} + \underset{(0.58)}{0.05\Delta p_{t-4}}$$

$\bar{R}^2 = 0.70$
$SEE = 0.0037$
$Q = 22.05$
$D.F. = 113$

(A.2′)
$$\Delta p_t = \underset{(2.62)}{0.021(y_t - y_t^f)} + \underset{(3.44)}{0.32\Delta p_{t-1}} + \underset{(3.51)}{0.33\Delta p_{t-2}} + \underset{(2.98)}{0.28\Delta p_{t-3}} + \underset{(0.86)}{0.07\Delta p_{t-4}}$$

RESTRICTION : In $\sum_{i=1}^{4} \delta_i \Delta p_{t-i}$, $\sum_{i=1}^{4} \delta_i \equiv 1.$

$F(1,113) = 4.63.$

$\bar{R}^2 = 0.69$
$SEE = 0.0038$
$Q = 23.20$
$D.F. = 115$

Equation (A.3) defines y^f, the log of full-employment real GDP, as the fitted values of a log linear time trend (T) of real GDP. This equation incorporates the idea, common to Keynesian models, that real GDP is trend stationary.

(A.3)
$$y_t^f = \underset{(846.15)}{7.56} + \underset{(98.9)}{0.007928\, T_t}$$

$\bar{R}^2 = 0.97$
$SEE = 0.0045$
$Q = 1662.32$
$D.F. = 119$

To test for the robustness of the results under a unit root in real GDP, we also estimate the following equation:

(A.3′)
$$\Delta y_t = \underset{(4.00)}{0.0051} + \underset{(2.56)}{0.24\Delta y_{t-1}} + \underset{(1.50)}{0.014\Delta y_{t-2}}$$

$\bar{R}^2 = 0.065$
$SEE = 0.0091$
$Q = 27.31$
$D.F. = 116$

Equations (A.4) and (A.5) represent the financial sector of the model, respectively defining the demands for the monetary base and M2 as functions of the aggregate price index, real GDP and a short-term nominal interest rate. As in Miller (1991), we find that M2 is cointegrated with these arguments, whereas the base is not. Thus the base demand equation is specified in first differences, while the M2 demand equation has an error correction form.

(A.4)
$$\Delta b_t - \Delta p_t = \underset{(0.42)}{0.00029} + \underset{(1.15)}{0.064\Delta y_{t-1}} + \underset{(3.40)}{0.17\Delta y_{t-2}} - \underset{(-7.86)}{0.42\Delta R_{t-1}} + \underset{(7.61)}{0.50(\Delta b_{t-1} - \Delta p_{t-1})}$$

$\bar{R}^2 = 0.54$
$SEE = 0.0050$
$Q = 22.83$
$D.F. = 115$

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(A.5)

$$\Delta m2_t = \underset{(-2.49)}{-0.079} - \underset{(-3.27)}{0.89 m2_{t-1}} + \underset{(3.27)}{0.89 p_{t-1}}$$

$$+ \underset{(3.27)}{0.95 y_{t-1}} - \underset{(-3.71)}{0.14 R_{t-1}} + \underset{(11.28)}{0.70 \Delta m2_{t-1}}$$

$$+ \underset{(1.93)}{0.17 \Delta p_t} - \underset{(-1.42)}{0.074 \Delta y_t} - \underset{(-4.56)}{0.26 \Delta R_t}$$

$$- \underset{(-2.83)}{0.016 cc_t} + \underset{(5.78)}{0.029 mm_t}$$

$\bar{R}^2 = 0.61$
$SEE = 0.0049$
$Q = 28.16$
$D.F. = 110$

The above equations were combined with the various feedback rules to form three simulation models that were used to generate results discussed in the text:

Nominal GDP/Interest Rate Simulation: Equation 1, with equations A.1, A.2, A.3, and A.4.

M2/Interest Rate Simulation: Equation 2, with equations A.1', A.2, A.3, and A.5.

Nominal GDP/Monetary Base Simulation: Equation 3, with equations A.1, A.2, and A.3.

Vector Autoregression-Error Correction Models

In addition to the model just discussed, we also conducted simulations using an atheoretic framework. For the case in which the monetary base is used as the instrument, we used the following variables: real GDP, the price level, the base and the nominal short-term interest rate. Following Johansen and Juselius (1990) we tested for cointegrating vectors in this system of variables. Finding none, we estimated a VAR with all variables in first differences. We selected lag lengths using the Final Prediction Error procedure (Judge, et al., 1985). The estimation results are summarized in Table A.1.

The VAR embodies no theoretical restrictions and therefore is agnostic about the structure of the economy. In simulating this model with the nominal GDP/Base rule, the estimated equation for the base was replaced by equation (3) defining the policy rule. This produced:

Nominal GDP/Monetary Base Simulation: Equation 1, together with the VAR equations for y, p, and R.

To evaluate the rules in equations 1 and 2, which use the interest rate as the instrument, we incorporated the following variables: real GDP, the price level, M2, and the

Table A.1

Marginal Significance Levels of Dependent Variables

	Δy	Δp	ΔR	Δb
Δy	.509	—	.000332	—
Δp	.018	.000	.168	—
ΔR	.00192	.0152	.898	.000
Δb	.666	.0366	—	.000
$\bar{R}^2$	0.36	0.71	.039	.063
SEE	0.0080	0.0036	.0077	0.0035
Q	26.55	26.60	43.18	27.85
$D.F.$	101	109	102	110

Table A.2

Vector Error Correction Model

	Dependent Variables			
	Δy	Δp	$\Delta m2$	ΔR
y_{t-1}	—	−0.033[a] (−1.66)	0.13[a] (3.80)	—
p_{t-1}	—	−0.033[a] (−1.66)	0.13[a] (3.80)	—
$m2_{t-1}$	—	0.033[a] (1.66)	−0.13[a] (−3.80)	—
R_{t-1}	—	0.028 (0.26)	−0.11 (−3.55)	—
	(Marginal Significance Levels)[b]			
Δy	.585851	.332590	.237394	.003320
Δp	.004468	.000000	.225075	.168222
$\Delta m2$	.037828	.585279	.000000	—
ΔR	.063848	.004459	.000037	.898220
$\bar{R}^2$	0.31	0.69	0.66	0.32
SEE	0.0078	0.0036	0.0046	0.0077
Q	34.13	17.44	28.60	43.18
$D.F.$	95	103	97	102

[a]Restriction of coefficient equality imposed.
[b]Lags chosen by Final Prediction Error procedure (Judge, et al., 1985).

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treasury bill rate. In this case, the Johansen-Juselius tests detected one cointegrating vector, which was statistically significant in the M2 and price equations. Given the signs and magnitudes of the coefficients in this vector, it appears to be a money demand equation. Moreover, the Johansen-Juselius test failed to reject the hypothesis that the coefficients on y, p and $m2$ were equal. The estimation results are summarized in Table A.2.

In simulations to evaluate equations 1 and 2, the interest rate equation above was replaced by the rule. This yielded:

Nominal GDP/Interest-Rate Simulation: Equation 1, together with VECM equations for y, p, and M2.

M2/Interest-Rate Simulation: Equation 2, together with VECM equations for y, p, and M2.

APPENDIX B
SENSITIVITY ANALYSIS: 1960–1989

Table B.1

Rule: Nominal GDP/Monetary Base
Model: Keynesian

	Dynamic Stability[a]	95% Confidence Limits[b]: Average Inflation	95% Confidence Limits[b]: Four-Quarter Real GDP Growth
1. **Basic Model**	107	−0.4% to 0.3%	−3.4% to 10.0%
Modifications			
2. (A.2′):			
In $\sum_{i=1}^{n} \delta_i \Delta p_{t-i}$, $\sum_{i=1}^{n} \delta_i \equiv 1$	80	−1.1% to 0.4%	−8.9% to 12.6%
3. (A.2):			
One lag of Δp_{t-i}	107	−0.4% to 0.3%	−6.0% to 12.7%
Eight lags of Δp_{t-i}	107	−0.3 to 0.3	−2.8 to 9.6
4. (A.2):			
$\partial \Delta p / \partial (y - y^f)$			
$+2\sigma$	106	−0.4% to 0.1%	−4.3% to 11.0%
-2σ	107	−0.1 to 1.3	−3.1 to 9.8
5. (A.1):			
$\partial \Delta y / \partial (\Delta b - \Delta p)$			
$+2\sigma$	94	−0.4% to 0.6%	−3.7% to 10.3%
-2σ	81	−0.5 to 0.6	−9.9 to 11.0
6. (A.3):			
Use (A.3′)	107	−0.4% to 0.2%	−3.6% to 10.0%

[a]This column reports the number of combinations of α and β that produced dynamically stable simulations out of a total of 107 combinations tried.
[b]Simulations use $\alpha = 0.50$ and $\beta = 0.00$.

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Table B.2

Rule: Nominal GDP/Interest Rate
Model: Keynesian

	Dynamic Stability[a]	95% Confidence Limits[b]: Average Inflation	Four-Quarter Real GDP Growth	One-Quarter Interest Rate Change
1. **Basic Model**	82	−1.3% to 0.9%	−6.3% to 19.7%	−3.7% to 3.8%
Modifications				
2. (A.2′):				
In $\sum_{i=1}^{n} \delta_i \Delta p_{t-i}$, $\sum_{i=1}^{n} \delta_i \equiv 1$	14	Explosive	Explosive	Explosive
3. (A.2):				
One lag of Δp_{t-i}	77	−1.4% to 2.0%	−26.5% to 23.8%	−6.5% to 7.1%
Eight lags of Δp_{t-i}	77	−0.6 to 1.0	−5.7 to 10.3	−2.5 to 3.0
4. (A.2):				
$\partial \Delta p / \partial (y - y^f)$				
$+2\sigma$	70	−1.4% to 3.0%	−38.3% to 17.5%	−6.0% to 6.8%
-2σ	81	−0.5 to 1.6	−3.9 to 11.5	−2.4 to 3.1
5. (A.1):				
$\partial \Delta y / \partial (\Delta b - \Delta p)$				
$+2\sigma$	38	−0.7% to 0.6%	−7.5% to 15.4%	−2.7% to 3.2%
-2σ	95	−1.2 to 2.7	−13.4 to 12.4	−5.6 to 6.3
6. (A.4):				
$\partial (\Delta b - \Delta p) / \partial \Delta R$				
$+2\sigma$	49	−1.5% to 1.4%	−8.4% to 19.7%	−4.7% to 5.2%
-2σ	101	−1.0 to 0.7	−5.7 to 15.8	−3.1 to 3.2
7 (A.3):				
Use (A.3′)	72	−1.1% to 0.8%	−9.1% to 16.1%	−3.8% to 4.0%

[a]This column reports the number of combinations of α and β that produced dynamically stable simulations out of a total of 107 combinations tried.

[b]Simulations use $\alpha = 0.25$ and $\beta = 0.50$.

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Table B.3

Rule: Nominal GDP/Interest Rate
Model: Keynesian; Derivative Control Only

	Dynamic Stability[a]	95% Confidence Limits[b]: Average Inflation	Four-Quarter Real GDP Growth	One-Quarter Interest Rate Change
1. **Basic Model**	7	−2.3% to 4.9%	−1.3% to 8.2%	−1.1% to 1.3%
Modifications				
2. (A.2′):				
In $\sum_{i=1}^{n} \delta_i \Delta p_{t-i}$, $\sum_{i=1}^{n} \delta_i \equiv 1$	1	−6.6% to 6.3%	−2.6% to 11.7%	−1.8% to 1.8%
3. (A.2):				
One lag of Δp_{t-i}	7	−1.9% to 4.9%	−2.2% to 8.9%	−1.4% to 1.7%
Eight lags of Δp_{t-i}	7	−1.9 to 5.2	−2.7 to 9.3	−1.0 to 1.3
4. (A.2):				
$\partial \Delta p / \partial (y - y^f)$				
$+2\sigma$	7	−2.9% to 4.2%	−1.7% to 8.2%	−1.3% to 1.5%
-2σ	7	1.0 to 5.7	−1.5 to 7.2	−0.8 to 1.5
5. (A.1):				
$\partial \Delta y / \partial (\Delta b - \Delta p)$				
$+2\sigma$	5	−0.7% to 4.8%	−2.3% to 9.3%	−1.0% to 1.5%
-2σ	8	−4.3 to 5.3	−0.9 to 7.4	−1.3 to 1.3
6. (A.4):				
$\partial (\Delta b - \Delta p) / \partial \Delta R$				
$+2\sigma$	8	−2.4% to 6.3%	−8.0% to 3.3%	−1.1% to 1.5%
-2σ	6	−1.6 to 4.0	−1.7 to 8.3	−1.1 to 1.3
7 (A.3):				
Use (A.3′)	7	−2.0% to 4.9%	−1.9% to 8.1%	−1.1% to 1.4%

[a]This column reports the number of values of β that produced dynamically stable simulations out of a total of 8 trials.
[b]Simulations use $\alpha = 0.00$ and $\beta = 0.50$.

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Table B.4

Rule: Nominal GDP/Interest Rate
Model: Vector Error Correction

	Dynamic Stability[a]	95% Confidence Limits[b] Average Inflation	Four-Quarter Real GDP Growth	One-Quarter Interest Rate Change
1. **Basic Model**	21	−1.0% to 2.5%	−11.7% to 19.8%	−2.5% to 2.7%
Modifications				
2. $\Delta M2$ Equation:				
Coefficients on $M2$, p, and y				
$+2\sigma$	10	−0.8% to 5.1%	−49.7% to 3.8%	−2.3% to 3.6%
-2σ	13	−6.4 to 1.6	−42.2 to 199.2	−8.5 to 6.3
3. Δp Equation:				
Coefficients on $M2$, p, and y				
$+2\sigma$	0	Explosive	Explosive	Explosive
-2σ	14	−3.0% to 0.1%	−79.9% to 11.6%	−20.4% to 21.2%
4. $\Delta M2$ Equation:				
Coefficient on R				
$+2\sigma$	7	−5.0% to 3.3%	−3.4% to 40.8%	−3.0% to 2.5%
-2σ	17	−1.3 to 1.9	−23.9 to 33.0	−4.0 to 4.0

[a]This column reports the number of combinations of α and β that produced dynamically stable simulations out of a total of 107 combinations tried.
[b]Simulations use $\alpha = 0.25$ and $\beta = 0.50$.

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Table B.5

Rule: Nominal GDP/Interest Rate
Model: Vector Error Correction; Derivative Control Only

	Dynamic Stability[a]	95% Confidence Limits[b]: Average Inflation	Four-Quarter Real GDP Growth	One-Quarter Interest Rate Change
1. **Basic Model**	7	−0.3% to 3.1%	−0.6% to 10.2%	−0.9% to 1.1%
Modifications				
2. Δ*M2* Equation: Coefficients on *M2*, *p*, and *y*				
+2σ	8	−8.8% to 12.5%	−2.1% to 11.3%	−0.4% to 1.6%
−2σ	8	−5.1 to −2.2	−2.2 to 7.9	−1.2 to 0.8
3. Δ*p* Equation: Coefficients on *M2*, *p*, and *y*				
+2σ	0	Explosive	Explosive	Explosive
−2σ	8	−6.4% to −3.4%	−0.7% to 8.4%	−1.3% to 0.8%
4. Δ*M2* Equation: Coefficient on *R*				
+2σ	8	4.4% to 8.9%	−2.0% to 7.0%	−0.6% to 1.4%
−2σ	8	−1.0 to 2.2	−0.6 to 9.4	−1.0 to 1.0

[a]This column reports the values of β that produced dynamically stable simulations out of a total of 8 trials.
[b]Simulations use $\alpha = 0.00$ and $\beta = 0.50$.

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