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ABSTRACT

This paper studies the possibility of using the broad monetary aggregate M2 to target the quarterly rate of growth of nominal GDP. Our findings indicate that the Federal Reserve could probably guide M2 in a way that reduces not only the long-term average rate of inflation but also the variance of the annual rate of growth of nominal GDP. An optimal M2 rule, derived from a simple VAR, reduces the mean ten-year standard deviation of annual GDP growth by over 20 percent. Although there is uncertainty about this value because of both parameter uncertainty and stochastic shocks to the economy, we estimate that the probability that the annual variance would be reduced over a ten year period exceeds 85 percent.

A much simpler policy based on a single equation linking M2 and GDP is shown to be almost as successful in reducing this annual GDP variance. Additional statistical tests indicate that M2 is a useful predictor of nominal GDP. Moreover, a battery of recently developed tests for parameter stability fails to reject the hypothesis that the M2 - GDP link is stable, but the MI - GDP and monetary base - GDP relations are found to be highly unstable. This evidence contradicts those who have argued that the M2 - GDP relation is so unstable in the short run that it cannot be used to reduce the variance of nominal GDP growth.

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This paper examines the feasibility of using a monetary aggregate to influence the path of nominal GDP with the ultimate goal of reducing the average rate of inflation and the instability of real output. We measure the strength and stability of the link between the broad monetary aggregate (M2) and nominal GDP and we assess the likelihood that an active rule for modifying M2 growth from quarter to quarter would reduce the volatility of nominal GDP growth.

Our general conclusion is that the relation between M2 and nominal GDP is sufficiently strong and stable to warrant a further investigation into using M2 to influence nominal GDP in a predictable way. The correlation between nominal GDP and past values of M2 is, of course, relatively weak, so the ability to control nominal GDP is far from perfect. Nevertheless, the evidence suggests that a simple rule for varying M2 in response to observed changes in nominal GDP would reduce the volatility of nominal GDP relative to both the historic record and the likely effect of a passive constant-money-growth-rate rule. Our calculations indicate that the probability that this simple rule reduces the variance of annual nominal GDP growth over a typical decade is 85%.

The paper begins in section 1 with a discussion of the goals of monetary policy and of the specific form in which we shall assess the success of alternative monetary rules. Section 2 presents several alternative monetary policy rules that will be evaluated in the paper. Section 3 then discusses three issues that must be resolved if a monetary aggregate is to be useful for targeting nominal GDP. These include not only the strength and stability of the link between nominal GDP and M2 but also the apparent inability of the Federal Reserve to control M2 in the short-term and the risk that a more explicit use of a monetary aggregate to target nominal GDP would weaken the statistical relationship that we have found in the historic evidence (i.e., the so-called "Goodhardt's Law" problem).

In section 4 we present evidence about the strength of the link between M2 and nominal GDP and discuss Granger causality tests for the entire sample and for subsamples. Section 5 presents more explicit tests of the stability of the link between M2 and nominal GDP. Our focus on M2 reflects a belief that a broad monetary aggregate is likely to have a stronger and more stable relation with nominal GDP than a narrower aggregate. We test this assumption in section 6 by examining the strength and stability of the link from the monetary base and M1 to nominal GDP, and find strong evidence of instability in both the base/GDP and M1/GDP relations. There is a large literature on the link from financial variables to output (recent contributions include Bernanke and Blinder (1992) and Friedman and Kuttner (1992)) and our results on the apparent usefulness and stability of the M2/GDP relation are at odds with some of it. As we explain, this is due to our focus on nominal rather than real output, to particulars of specification (we explicitly adopt an error-correction framework), and to our use of recently developed econometric tests for parameter stability.

Sections 7 and 8 then derive an optimal rule for targeting nominal GDP in a simple model and compare its performance with simpler alternative rules. Although a considerable amount has been written on the theory of nominal GDP targeting, fewer studies have examined the practical aspects of nominal GDP targeting; notable exceptions are Taylor (1985), McCallum (1988, 1990), Pecchenino and Rasche (1990), Judd and Motley (1991, 1992), and Hess, Small and Brayton (1992). The investigation in sections 7 and 8 is in the spirit of these studies, except that we focus on probabilistic statements about the size and likelihood of improvements resulting from using M2 to target nominal GDP. Section 9 examines the predictive validity of our M2-based time series models by comparing them with private forecasts. Section 10 then returns to the question of the Federal Reserve's apparent inability to control the M2 money stock and discusses how that problem could be remedied by broader reserve requirements with interest paid on those reserves.

1. The Goals of Monetary Policy

The widely agreed goals of monetary policy are a low rate of inflation ("price stability") and a small gap between actual real GDP and potential real GDP. There is general agreement that a low long-term rate of inflation can be achieved by limiting the rate of growth of a broad monetary aggregate sufficiently over a long enough period of time.

The monetary policy rules that we consider in this paper are all compatible with achieving any particular long-run average rate of inflation. Moreover, in the models that we consider, the short-term monetary policy rule that is selected does not affect the ability to achieve a low long-term average level of inflation. Technically, we are assuming that the Federal Reserve could set the long-run inflation rate by the identity that mean inflation equals mean money growth plus mean velocity growth less mean real output growth. Empirical evidence suggests that the long-run mean of the growth of M2 velocity is zero (a consequence of the long-run money demand functions reported in section 4). Although there is much interesting research on the relation between long-term real output and long-term money growth (a recent empirical contribution is King and Watson (1992)), the problem of setting the means is separate from the problem of short-term stabilization considered here. In this sense, any gains achieved by short-run stabilization are gains in addition to those achieved by choosing the average money growth rate which achieves low long-run inflation.

The general goal of reducing the gap between actual and potential GDP in the short and medium term can be made more precise in a variety of ways. This paper takes the approach of evaluating economic performance by the variance of the quarterly nominal GDP growth rate. This focus on the variance of nominal GDP implies giving equal weights to short-term variations of inflation and of real output. Alternative measures of short-term performance that might instead be used include the variance of real GDP growth and the mean shortfall of real GDP from potential GDP. Although such measures would ignore the short-term variation in inflation rates, the desired low long-run average rate of inflation would be assured by setting the appropriately low mean growth rate of the monetary aggregate.

Judging performance by the variance of the nominal GDP growth rate is equivalent to targeting the growth rate of nominal GDP rather than a path of nominal GDP levels. Although this distinction has no implication for the long-term inflation rate, it does affect the optimal response of policy to short-term shocks to the economy. In particular, the implicit desired future path of nominal GDP is always independent of the starting point.

This can be seen more clearly by contrasting the target of minimizing the variance of the nominal GDP growth rate (around its mean for the entire sample) with the alternative target of minimizing the variance of nominal GDP around a trend with an exponential rate of growth equal to the sum of the desired rate of inflation and the mean real GDP growth rate in the sample. If the economy starts on the trend line, the two criteria are the same for the first period. But any departure from the trend during the first period implies a different standard for the second period. The criterion of minimizing the variance of the nominal GDP growth rate ignores any "base drift" in nominal GDP. It can be thougth of as minimizing the variance around the trend line with the starting point of the trend rebased in each period to the actual level achieved in the previous period.

Which of the two approaches is preferable depends on the types of shocks that are most likely to be encountered, the differential effects of money on real output and inflation, and the ultimate objective of monetary policy. For example, if in the extreme real output is a random walk and unaffected by monetary policy then a nominal GDP level target will result in the price level being a random walk, so that the future price level will deviate arbitrarily far from its desired fixed level. On the other hand, minimizing quarterly fluctuations in the growth of nominal GDP will result in constant (say, zero) inflation and the future price level is stabilized. Similarly, if the growth rate of potential real GDP varies significantly from quarter to quarter, minimizing the variance of the growth rate would be the better policy. The alternative of minimizing the variance from a prespecified nominal GDP path would require a contractionary policy after a positive productivity shock even though there had been no increase in inflation and an expansionary policy after a negative productivity shock even though there had been no decrease in inflation. We have not explored this issue in the current research.

Our tests of the strength and stability of the link between M2 and nominal GDP are however relevant whether the criterion by which policy is judged is the variance of nominal GDP around its mean or the deviations of nominal GDP from a predetermined target path. The choice of criterion determines how the money stock should vary from quarter to quarter to minimize the relevant variance.

2. Alternative Approaches to Monetary Policy

Although the Federal Reserve is concerned with inflation and real economic activity, monetary policy must be made by adjusting some monetary variable – a monetary aggregate, an interest rate or the exchange rate. In this section we discuss three possible approaches. This is far from an exhaustive set of alternatives, but rather provides a context for comparing an M2 approach to nominal GDP targeting to other commonly discussed options.

2.1 The Status Quo: Judgmental Eclecticism

In practice, the Federal Reserve controls the volume of bank reserves (a monetary aggregate) by open market sales of Treasury securities. In recent years, the volume of such sales has been adjusted to target the value of the Federal funds interest rate. Thus, for time intervals up to several weeks, any disturbance in the statistical relation between the Federal funds rate and bank reserves (i.e., in the banking system's bivariate demand function for reserves) induces the Federal Reserve to alter reserves in order to maintain the desired level of the Federal funds rate. In this context, the interest rate is the exogenous variable and the volume of reserves is endogenous. For longer periods of time, the relationship is more ambiguous because the Federal Reserve's Open Market Committee (FOMC) may revise the Fed funds rate target in part in response to the magnitude of reserve growth and the corresponding movement of the narrow monetary aggregate M1 (as well as to other aspects of economic and financial performance).

It is significant that the FOMC now makes decisions and issues operating instructions to the New York Federal Reserve Bank in terms of the Federal funds interest rate and not in terms of

M2 or some other monetary aggregate. Each of the individual members of the FOMC may vote to increase or decrease the Fed funds rate for his or her own reasons. Some members see a reduction of the Federal funds rate as a way of increasing the rate of growth of M2 and therefore of subsequent nominal and real GDP. Others may ignore the potential impact on the money stock and choose an interest rate change because of what they regard to be the likely effect on inflation and real output.[1] At times, some FOMC members may consider the effect of changes in the Fed funds rate on the international value of the dollar. Still others may emphasize the psychological effect of changes in interest rates as an indication of the Fed's resolve to fight inflation or stimulate economic activity.

We do not try to model and test an explicit interest rate rule for monetary policy or any other complex judgmental rule. Rather we take the historic record of economic performance as indicative of what the Federal Reserve can achieve by such an eclectic judgmental policy. Technically many of the statistics we report, in particular the regression R^2's and tests for predictive content in sections 4 and 6 and the performance measures in sections 7 and 8, should be interpreted as providing evidence on the ability of alternative policies to improve upon past performance. Indeed, were past performance optimal in the sense that money had been used to minimize the variance of quarterly nominal GDP, then we would expect to find no historical correlation between money and future GDP growth. In contrast, were the historical M2/GDP relationship strong and stable, this would open the door to an investigation of whether this link could be exploited to control GDP more effectively than has been done historically.

2.2 Passive Monetary Policy: A Constant Growth Rate of M2

A natural starting place among explicit quantitative monetary rules is Milton Friedman's proposal for a policy of constant growth of the money supply. Setting the constant growth rate of money equal to the expected growth of potential GDP minus the expected rate of increase of velocity implies a zero expected rate of inflation. Small errors in the estimated rate of growth of either potential GDP or velocity causes correspondingly small departures of inflation from price stability.

Friedman argues that a constant rate of money growth is actually likely to result in a more stable path of nominal GDP than a more active monetary policy aimed at achieving such stability (Friedman (1953)). Friedman's argument can be summarized easily in the framework in which stability is defined as the variance of the growth rate of nominal GDP. Suppose that nominal GDP growth consists of two parts, one which would be achieved under a constant growth rule and one which reflects the impact of an activist rule. Then the variance of nominal GDP growth is the sum of the variances of these components, plus their covariance. Friedman's point is that activist policy reduces volatility only if the covariance is sufficiently negative to offset the additional variance contribution from activist control.

This decomposition provides a useful way to interpret the regression results elsewhere in the literature and in section 4. If M2 enters significantly, then necessary an optimal or nearly optimal policy can reduce total volatility. However, if the regression R^2 is small, then the gains from such control will be modest. Moreover, following the "wrong" policy can increase rather than decrease output volatility.

2.3 Active Targeting Rules for Monetary Policy

McCallum (1988, 1990), Taylor (1985) and others have developed and simulated alternative rules for managing monetary policy with the aim of stabilizing nominal GDP growth. We build on this literature in sections 7 and 8 of this paper by proposing an optimal rule for using monetary policy to target nominal GDP and a simple, partial-adjustment rule that approximates the effect of the optimal rule.

As part of our analysis of these rules, we calculate the probability that they would reduce the variance of nominal GDP growth. The specific calculation we perform addresses the following thought experiment: suppose the Federal Reserve were to adopt a particular nominal GDP targeting rule and use it for a decade. Based on the data available to us from 1959 to 1992, what is the probability that the variance of quarterly nominal GDP growth would be less over this ten-year span than it would be under the status quo? What is the expected percent reduction in the ten-year standard deviation of quarterly GDP growth under the rule and, more generally, what does the distribution of potential reductions look like? Our statistics answer these questions, and also quantify the distribution of ten-year variance reductions in two- and four-quarter growth of GDP. This calculation incorporates both the parameter uncertainty arising from working with a finite historical data set and the additional uncertainty introduced by different possible ten-year paths of future shocks to the economy. When the policy rule is designed to minimize quarterly GDP volatility, we refer to the performance measure applied to GDP as a performance bound, since by construction the monetary policy is designed to minimize the population (multiple decade, long data set) value of this ratio. Our calculations show that in principle the optimal M2 rule would have outperformed status quo policy with a rather high probability.

The complexity of the optimal rule for varying M2, even in the simple model that we analyze, suggests that explicit optimization is more relevant as a benchmark than as an actual prescription for application by the Federal Reserve. We therefore examine simpler partial-adjustment rules, which are in the spirit of the rules examined by Taylor (1985) and McCallum (1988, 1990). In particular, the rule for which we tabulate results adjusts M2 40% toward closing the gap between realized and desired nominal GDP growth. Performance measures for this simplified rule show that it would have resulted in nominal GDP stabilization close to that of the optimal rule and better than the implicit status quo policy. Moreover, long-run mean inflation would be reduced by choosing a lower mean money growth rate. Thus this rule could result in both lower mean inflation and reduced volatility of GDP growth, relative to the status quo.

3. The Usefulness of a Monetary Targeting Rule: Three Issues

The research in this paper shows that an active monetary rule of the type described in section 2.3 and studied in sections 7 and 8 can in principle achieve a more satisfactory economic performance (as measured by the rate of inflation and the stability of nominal GDP growth) than has been achieved by the "eclectic judgmentalism" currently practiced by the Federal Reserve or than would be achieved by the passive policy of constant M2 growth proposed by Milton Friedman. We show also that the professional forecasters do not appear to have an advantage relative to a simple M2-based VAR model at forecasting nominal GDP and therefore conclude tentatively that monetary activism based on professional forecasts may be no more satisfactory than policies based on simpler forecasting models.

The conclusion that a monetary rule can "in principle" be useful reflects our finding of a sufficiently stable link between money and nominal GDP. Two other issues must be resolved favorably in order to conclude that monetary targeting would be useful in practice as well as in principle. Briefly, the three requirements for the usefulness of a monetary targeting rule can be characterized as: (1) a sufficiently stable link between money and nominal GDP; (2) satisfactory behavior of the Federal Reserve; and (3) a limited system response to the change in monetary policy.

3.1 A Stable Link Between Money and Nominal GDP

The statistical tests presented in section 4 and 5 show that M2 has predictive content for nominal GDP and that the relationship appears to have been stable over time. More precisely, section 4 shows that the link between money and nominal GDP exists for the entire thirty-year sample. It is strong enough so that Milton Friedman's case against active policy cannot be based on the absence of an adequate link between short-run variations of M2 and nominal GDP. The evidence in Section 5 suggests that the parameters have been stable in the sense that we cannot reject the null hypothesis of parameter constancy using several recently proposed tests for parameter stability.

3.2 Satisfactory Behavior of the Federal Reserve

Milton Friedman and others base their argument against an activist monetary policy in part on the claim that there is an inherent inflationary bias in central bank behavior: even if the Federal Reserve could control M2 completely and knew an optimizing rule for setting M2, they would violate that rule because of political pressures or other reasons.

There is of course no way to answer that criticism fully. We do note however that the Federal Reserve and other central banks around the world have over the past decade been pursuing relatively tough anti-inflationary policies and that those central banks with greater independence have pursued that goal more aggressively. That is no guarantee about the future behavior of the Federal Reserve. Those who believe that any central bank that has discretion will eventually act incompetently or perversely may or may not be right, but they cannot be persuaded by evidence.

Nevertheless, if our evidence on the predictive link between money and nominal GDP is accepted, those who would still advocate a passive fixed-money-growth rule would have to argue that the gain in terms of reduced inflation that results from such a policy outweighs the potential benefit in terms of output stability that can be achieved by an active rule-based monetary policy.

It seems likely, moreover, that any policy based on an explicit quantitative rule is less subject to political and other pressures than the purely judgmental approach currently pursued by the Federal Reserve. Perhaps it would be a useful further discipline if the Federal Reserve were to state the rule publicly and to explain to the financial and policy community whenever monetary policy did not conform to the rule over a period of, for example, six months, just as the Federal Reserve now announces a target range for money growth and must explain to Congress whenever it fails to achieve money growth in that range.

In addition to the question of the Federal Reserve's willingness to use a monetary rule to target nominal GDP, there is also a more technical aspect about the Federal Reserve's ability to act in compliance with a rule that requires managing quarterly changes in M2. Recent experience shows that conventional short-run money demand equations have broken down (Feinman and Porter (1992)). Evidently the Fed has been unable to estimate the volume of open market operations needed to achieve its desired changes in M2. For example, the increase of M2 at a rate of only 2.2 percent from the fourth quarter of 1991 to the fourth quarter of 1992 was below the lower end of the Fed's target range (2.5 percent to 6.5 percent) at a time when most Fed officials acknowledged that faster M2 growth would have been desirable. We return to this problem in section 10 and explain that the Federal Reserve could control M2 by expanding reserve requirements to include all of the components of M2. Until then, we will ignore the difference between controlling reserves and controlling M2 and will assume that the Federal Reserve can control the growth of money from quarter to quarter.

3.3 A Limited System Response to the Change in Monetary Policy

Even if the relation between money and nominal GDP has been stable in the past, an attempt to exploit that relation in an optimizing mode could cause a change in these reduced form parameters. Continuing to assume the old parameter values would lead to suboptimal results that could, in principle, be worse than those implied by the existing judgmental policies.

There are two sources of this possible instability. First, as discussed in section 10, to control M2 effectively would entail placing reserve requirements on its components. To the extent that this changes the M2/nominal GDP relation, the historical correlations upon which our analysis is based would become less useful. While this effect might take some time to detect, in principle these relations could be updated using new data and the policy rule modified to account for the effect of consistent reserve requirements.

The second source is more problematic, and concerns the empirical relevance of the Lucas critique of all policy analysis. One extreme form of this concern (suggested in a British context by Charles Goodhardt and known as "Goodhardt's Law") is that trying to use M2 (or any other aggregate) to target nominal GDP would break the causal link with nominal GDP and make controlling M2 irrelevant. Because we use an explicitly reduced-form model, our calculations are an obvious target for this critique. However, all extant empirical macro models are approximations -- there is no compelling reason to think that any empirical macroeconomic model incorporates the "deep parameters" stable to policy interventions -- so this criticism is equally applicable to all exercises in this area. The empirical relevance of the Lucas critique has been the topic of considerable debate (see for example Sims (1982, 1986)), and we have little to add on this topic. Yet, we note that the tests of sections 5 and 6 suggest that the M2/GDP relation -- unlike the M1/GDP relation, the monetary base/GDP, and the relation between various interest rates and output -- has been stable over the past thirty years, a period which has experienced several shifts in Fed operating procedures. More generally, the research of Friedman and Schwartz (1963) that originally established the existence of a link between money and nominal GDP covered a much longer period of time with even more substantial changes in monetary policy and economic institutions. This gives reason to hope that further changes to monetary policy would have limited effects on this relationship. These concerns do, however, imply that the relation between nominal GDP and M2 should be closely monitored were the Fed to change its the approach to monetary policy.

4. Strength of the Link from M2 to Nominal GDP

The question taken up in this section is whether M2 has predictive content for future nominal GDP growth. We address this by considering quarterly historical time series data on money, output, interest rates and prices over the period 1959:1 - 1992:2. (Data sources and transformations are detailed in Appendix A.) Visual inspection of the time series data from 1959:1 - 1992:2, portrayed in figure 1, indicates a link between the four-quarter growth in M2 and nominal GDP over the business cycle and indeed over longer periods. However, there appears to be less correlation between M2 and either inflation or real GDP growth.

Econometric evidence on the predictive content of various monetary aggregates for nominal GDP is presented in table 1. Each row of the table corresponds to a regression of nominal

GDP growth on a constant and three lags of the indicated variable. As discussed in Appendix A, in these regressions nominal GDP, real GDP, the GDP deflator, and M2 appear in growth rates; individual interest rates appear in first differences; and spreads appear in levels. The first numeric column of table 1 provides the $\bar{R}^2$ of the regression of the quarterly growth of nominal GDP against the first through fourth lag of the indicated regressors. The second and third columns report the $\bar{R}^2$'s from regressions of two- and four-quarter growth (current quarter growth plus growth over the next, or the next three, quarters), respectively, against the same set of regressors. The final columns report the results of F-tests for predictive content (Granger causality tests) for M2 and other financial variables entering the regressions.

The results in table 1 suggest that, over the 1959-1992 sample, there has been a systematic relationship between M2 and nominal GDP: M2 is a statistically significant predictor of nominal GDP growth at the 1% level in those regressions which include M2 or M2 in conjunction with inflation and interest rates. M2 is capable of predicting a statistically significant yet quantitatively modest amount of the movements in output at the one-quarter horizon; for example, the regressions in rows 7 and 8 indicate that M2 improves the one-quarter $\bar{R}^2$, relative to using lagged real GDP growth and lagged GDP inflation, by 0.127. However, at the four-quarter horizon the improvement from using M2 is more substantial, increasing the $\bar{R}^2$ of that regression from .092 to .326. In contrast, while the regressions with interest rates alone (equation 9 and 10) have comparable if somewhat smaller $\bar{R}^2$'s at the one-quarter horizon, their $\bar{R}^2$'s at the four-quarter horizon are less than .18.

A conventional question in the literature on the money-output relationship is whether the inclusion of interest rates eliminates the predictive content of M2 (e.g. Sims (1972, 1980)). For the current purposes, if true this would suggest that interest rates would make a more appropriate control variable than M2. The results in table 1 indicate that, for nominal GDP, this is not the case. For example, when the 90-day T-bill rate or the Fed funds rate is added to the regression in row 8, M2 remains statistically significant; in fact, the $\bar{R}^2$ for the four-quarter regression declines because of the inclusion of these additional interest rates which evidently have no additional predictive content at this horizon.

The specifications discussed so far only incorporate short-run relationships, in the sense that they relate growth rates to growth rates or changes. However, there is substantial evidence that there is a long-run relationship between the levels of money and output (both in logs) and interest rates, which can be thought of as a long-run money demand relation. Unit root tests suggest that velocity and interest rates can be treated as being integrated of order one, and cointegration tests suggest that these two variables are cointegrated (see for example Hafer and Jansen (1991), Hoffman and Rasche (1991), and Stock and Watson (1989a)); thus long-run money demand can be thought of as a cointegrating relation among these vectors. If so, then a candidate for inclusion in these output regressions is the "error correction" term which is the residual from the long-run money demand relation. Previous investigations suggest that a unit income elasticity is appropriate (see Stock and Watson (1989a) for results and a discussion), so the money demand cointegrating vector is specified here is $ZMD_t = \ln(X_t/M_t) - \beta_r R_t$, where X_t is log nominal GDP, M_t is log nominal money, and R_t is the level of the interest rate, here taken to be the 90-day Treasury bill rate. The interest semi-elasticity of money demand, β_r, was estimated by asymptotic maximum likelihood using the Phillips-Loretan (1992)/Saikkonnen (1991)/Stock-Watson (1989a) procedure, and one lag of the resulting estimate of ZMD_t was entered as an additional regressor in the specifications in table 1.[2] Thus these regressions correspond to a single-equation error correction model (see for example Hendry and Ericsson (1991)). Although this motivation for including ZMD stems from the theory of cointegration, this term has a natural interpretation in a regression of nominal output growth on money: it controls for deviations in velocity from its long-run value as determined by the interest rate.

The results in table 1 indicate that the long-run money demand residual has noticeable predictive power; for example, adding ZMD to regression 11 improves the one-quarter $\bar{R}^2$ by .063 and improves the four-quarter $\bar{R}^2$ by .078. When the money demand residual is included in the regression, the hypothesis that money does not enter implies that the lagged first differences *and* the money demand residual do not enter; thus in the regressions with ZMD the Granger causality tests for M2 in table 1 test both sets of exclusions (on all lags of M2 growth and on lagged ZMD). The hypothesis that M2 is statistically insignificant in the one-quarter horizon continues to be rejected in these regressions.

Despite this statistical significance for M2 in these regressions, it should be emphasized that the $\bar{R}^2$'s for these regressions are all rather low. For example, an $\bar{R}^2$ for a four-quarter horizon of 39% (equation 13) indicates that the ratio of the RMSE from using this regression, relative to using a constant forecast, is only .78. Looking ahead to the question of whether M2 can be used to further reduce the fluctuations in GDP, this inherent relative unpredictability of nominal GDP growth over the past three decades places a limit on any gains from modifying the control of M2 relative to the Fed's historical behavior.

Most of the recent research has focused on the relation between money growth and real, rather than nominal, output (e.g. Bernanke and Blinder (1992), Friedman and Kuttner (1989, 1992a), Stock and Watson (1989b)). As a basis of comparison, we therefore present econometric evidence on the predictive content of M2 for real GDP growth in table 2. In the case of real GDP growth, money has substantial predictive content and continues to enter each of the regressions at the 1% level.

It is interesting to note that M2 is significant even in the regression with the commercial paper-Treasury bill spread. Other authors, in particular Friedman and Kuttner (1992a, 1992b) (also see Bernanke (1992)), have found that the inclusion of this spread in similar regressions has eliminated the predictive content of money. The main difference between those results and the results in table 2 is that the F-tests in table 2 include the lagged money demand cointegrating residual, as well as lags of money growth; the F-statistic on the three lags of money growth alone in the table 2 regression with the paper-bill spread is 1.68 which, with a p-value of .175, is not significant at the 10% level. However, the t-statistic on the cointegrating residual in this regression is 3.23, and the joint F-test is significant. This phenomenon is present in the corresponding nominal GDP regression with the paper-bill spread, in which the F-test on the lags of money alone is 1.76 (p-value .16) and the t-statistic on ZMD is 3.71. In all other regressions in table 1, however, the F-test on just the lags of M2 growth is significant at the 5% level.[3] This statistical significance of the money demand residual agrees with recent independent results obtained by Konishi, Ramey and Granger (1992), who find that the logarithm of M2 velocity is a significant predictor of real GNP growth; however, Konishi, Ramey and Granger use M2 velocity and thus impose a long-run interest semielasticity of money demand of zero rather than estimating it as we do here.

The generally low predictive content of interest rates for nominal GDP contrasts with the findings for real GDP. For example, the regression of real output growth on lags of NGDP, PGDP, R-90, and the G10_G1 (the Treasury yield spread) has a four-quarter $\bar{R}^2$ of .384, while its four-quarter $\bar{R}^2$ for nominal GDP is only .192. This is consistent with previous results in the literature that emphasize the value of the slope of the yield term curve as a forecaster of real output (Estrella and Hardouvelis (1991), Stock and Watson (1989c, 1990)).

5. Stability of the link from M2 to Nominal GDP

This section examines the stability of the direct link from M2 to nominal GDP. In their investigation of the M2/output relation Friedman and Kuttner (1992a) concluded that much of the full-sample predictive content of money for both nominal and real income was attributable to the 1960's, a finding which they attributed to disintermediation during the 1970's and 1980's. As a starting point, we therefore consider whether the main findings of section 4 are robust to using the shorter sample with Friedman and Kuttner's (1992a) starting date of 1970:3.

Table 3 presents the summary statistics of table 1, evaluated over the more recent sample. In general, M2 has somewhat less predictive content in the later sample, although the deterioration in forecasting performance is modest. For example, the four-quarter $\bar{R}^2$ for the regression with lagged nominal GDP growth and lagged M2 growth is .30 in the full sample and is .25 in the later sample. The Granger causality test statistics indicate that M2 continues to be significant, albeit only at the 5% level in most regressions rather than at the 1% level found in table 1. Because this sample period is only two-thirds the length of the full sample, one would not expect to find as strong statistical significance of the monetary variables as over the full sample even if the relationship is stable. For this reason, a more useful statistic is the marginal $\bar{R}^2$'s from adding money to the regressions. While the increases remain economically significant, they drop in the later sample: at the four-quarter horizon, in the regression with nominal GDP, inflation, and the 90-day Treasury bill rate, over the full sample M2 alone has a marginal $\bar{R}^2$ of .149 and, in conjunction with ZMD, of .227; over the later subsample, these marginal $\bar{R}^2$ are, respectively, .073 and .185. In the later sample, when interest rates, M2, and ZMD are included, interest rates are never significant at the 5% level, while M2 and ZMD are jointly significant at the 5% level in all regressions.

The results in table 3 contrast with the findings of Friedman and Kuttner (1992a). Although the primary focus of their investigation was real output, their table 1 presents results on forecasts of nominal GNP. One of their conclusions was that, over the 1970:3 - 1990:4 sample, M2 ceased to be a significant forecaster of nominal GNP. In a mechanical sense, the difference between their findings and ours is explained, in order of importance, by: (i) our inclusion of the error correction term ZMD; (ii) the choice of lag length; and (iii) the slight difference in sample periods.[4] If, as argued in section 4, the cointegrated model applies, then the error correction term should be included in the regression, and because ZMD includes M2 a test of whether M2 Granger causes output should test both lags of M2 growth and the error correction term. Concerning lag length, in the regression on GDP and M2 growth, the first lag of M2 is significant but the others, considered one at a time, are not, and a joint test of significance of the fourth lags in the regression suggests choosing the shorter specification. The effect of including the final six quarters in the sample suggest that the recent slow growth of nominal output and M2 in the face of low and declining interest rates and a sharply inverted yield curve has tilted the results somewhat towards M2 as a predictor. While we therefore prefer the specifications in table 3, those results and Friedman and Kuttner's (1992a) findings suggest investigating further the question of whether the M2/nominal output relation is stable. The differences between our findings and Friedman and Kuttner's ultimately point to the limitations of simple regression statistics, and that information of a different type is needed on the stability of this relationship.

We therefore subject these relations to a series of formal tests for parameter stability. The overall purpose of these tests is to detect parameter instability when the type of instability is unknown *a-priori*. If it were presumed that a break might have occurred at some known date, then the simplest test for such a break would be a Chow-type test for a shift in the parameters. However, in practice the date at which the break occurred is typically unknown *a-priori* and the candidate break date is based upon knowledge of the historical data. In this case, the subsequent test statistic does not have its classical sampling distribution, and the precise sampling distribution will depend on the preliminary method used to select the break date. (Christiano (1992) provides an empirical example of this point; for the associated econometric theory, see the July 1992 special issue of the *Journal of Business and Economic Statistics* on unit root and break-point tests.) The test statistics considered here handle this difficulty by explicitly treating the break date as unknown.

Three classes of tests are considered. These tests are described in Appendix B and are briefly summarized here. Tests in the first class look for a single structural break which occurred at an unknown date during the sample. These tests are based on the sequence of likelihood ratio statistics testing the hypothesis that the break occurred in quarter k. The most familiar of these tests is the Quandt likelihood ratio statistic (the "QLR" statistic), which is the maximum over k of these likelihood ratio statistics; the other two tests are the average of the likelihood ratio statistics ("Mean-Chow") and an exponential average of these proposed by Andrews and Ploberger (1991) ("AP Exp-W"). As discussed by Andrews and Ploberger (1991), these tests are designed to have good power properties against a single break in one or more of the regression coefficients. These tests are implemented with trimming parameter $\lambda = .15$ (see Appendix B). For comparison purposes, we also report the value of the conventional Chow test, testing for a single break occurring in 1979:3 ("Chow"). However, this date is conventional in the literature precisely because is associated with the Fed's change in operating procedures *and* the double recessions of 1979-1982. Because this break date is at least in part data-dependent, conventional critical values are inappropriate and proper p-values are not readily ascertained.

Tests in the second class are similar in spirit to the Brown-Durbin-Evans CUSUM statistic, except that the statistics here are computed using the full-sample residuals as suggested by Ploberger and Kramer (1992a, 1992b). These tests are the maximum of the squared scaled partial sum process of the residuals ("P-K max") and its average ("P-K meansq"). These tests mainly have power against breaks in the intercept in the regression in question.

Unlike the previous tests, the final class of statistics are derived to have power against continuously shifting parameters. These tests, due to Nyblom (1989), are derived as LM tests of the null of constant coefficients against the alternative that the regression coefficients follow a random walk, although they also have power against single-break alternatives. Two versions of these tests are considered: the L-all statistic tests the hypothesis that all the regression coefficients are constant against the random walk alternative, while the L-fin statistic only tests the constancy of the coefficients on the financial variables (money, interest rates, spreads, and the money demand cointegrating residual). In practice, these tests often yield different inferences. Because the various tests were derived to have power against different alternatives, when used together they can provide insights into which types of instabilities, if any, are present in these regressions.

The results of these tests are presented in table 4 for the nominal GDP forecasting regressions in table 1. In all the M2 regressions but one, the only tests which reject at the 5% level are the Ploberger-Kramer tests (ignoring the fixed-Chow test, for which we cannot compute proper critical values because of the partly endogenous break date). This suggests that the constant term in several of these regressions is unstable, but that the coefficients on the stochastic regressors do not exhibit statistically significant shifts. The only case in which another test rejects at the 5% level is for regression 5, which includes both the Fed funds rate and the 90-day Treasury bill rate FYGM3: the QLR test rejects with an estimated break in

80:3. Since neither regressions 3 nor 4 reject using this statistic, this suggest that there might be some instability in the relationship between the Fed funds-T-bill spread and nominal output. This spread moves with other private-public spreads (Stock and Watson (1990)); in this light, its instability is consistent with the 10% rejection of the QLR statistic in regression 16, which includes the commercial paper-Treasury bill spread. Aside from these two regressions with the private-public yield spreads, the results suggest stable regression coefficients on the stochastic variables.[5]

Overall, the results of this section suggest that the predictive content of M2 (as well as other financial variables) for nominal GDP is somewhat less over the 1970-1992 subsample than over the full period. However, formal tests for parameter instability fail to reject the hypothesis that the M2 - GDP regressions have stable coefficients over the thirty-year sample, except perhaps for a shift in the intercept.

6. Links from other monetary aggregates to Nominal GDP

At various times, the Federal Reserve has considered employing alternative financial instruments as control variables, such as the monetary base, M1, and interest rates. In this section, we examine the predictive content of these other instruments for nominal GDP growth and the stability of these forecasting relationships.

Casual evidence suggests that the link from other monetary aggregates to output is less stable. The Federal Reserve is required by law to announce target ranges for monetary aggregates. In recent years, the Federal Reserve has provided target ranges for M2 and M3 as well as for a broader debt aggregate, but no longer provides a target range for M1. Federal Reserve officials argue that the payment of interest on most checking accounts (a component of M1) has increased the substitutability between M1 accounts and the components of M2 and therefore greatly increased the volatility of M1 velocity. In the first two quarter of 1992, for example, at annual rates M1 grew 13.4 percent while nominal GDP increased only 5 percent.

Annual growth rates of the monetary base and of nominal GDP, real GDP, and GDP inflation are plotted in figure 2. In figure 3, the monetary base is replaced by M1. In contrast to figure 1, no clear cyclical link is evident between either the base or M1 and and nominal output.

To investigate these links more formally, we apply the statistics described in sections 4 and 5 to regressions involving base money and M1. Evidence on the predictive content of base money and M1 is presented in tables 5 and 6.[6] The most striking feature of these results is that the predictive content of these regressions is substantially less than the corresponding regressions with M2, with four-quarter $\bar{R}^2$'s in the range 0.09 - 0.20, compared with $\bar{R}^2$'s in table 1 of almost 0.40. In the regressions with interest rates, the monetary base fails to be statistically significant at the 5% level, and M1 is no longer significant at the 10% level.

The stability of the base, M1, and interest rate regressions are examined in tables 7 and 8 using the tests for parameter constancy described in section 5. The hypothesis of parameter constancy is rejected overwhelmingly for base money, with every regression having at least one statistic which rejects stability at the 1% level. The evidence against stability for M1 is equally strong. Interestingly all the rejections for M1 result from the break-point tests rather than from Nyblom's (1989) tests for time varying parameters, suggesting a regime-shift in the parameters rather than a slow evolution. In both the base and M1 regressions, the break date is estimated to be in the early 1980's, perhaps reflecting the widespread introduction of interest-bearing checkable deposits during this period. In contrast, the regressions with interest rates only in table 4 suggest that the interest rate relations are relatively stable. The instability of the base and M1 regressions provide some insight as to why the base and M1 are insignificant when interest rates are also included in the regressions: even if these variables have predictive content, the nature of that predictive content varies over time and the more stable interest rate relations "drive out" the two narrow monetary aggregates.

Several conclusions emerge from these results. Neither M1 nor the monetary base have substantial predictive content for GDP over the full 1959-1992 sample, and both aggregates are no longer significant once interest rates are included in the regressions. Moreover, the link between these two aggregates on the one hand and nominal GDP growth on the other is unstable, with the stability tests rejecting in most specifications at the 1% level. While the link between interest rates and GDP growth appears to be more stable (with the exception of the term structure spread), the predictive content of interest rates for nominal GDP growth is substantially less than that of M2.

7. Optimal Nominal GDP Growth-rate Targeting: Performance Bounds

7.1 Methodology

We now turn to the task of estimating what the volatility of key economic variables would be, were the Federal Reserve to follow a nominal GDP targeting rule. Answering hypothetical questions such as this is central to the empirical analysis of macroeconomic policies. A standard approach to answering such questions, which we employ, is to adopt an empirical macroeconomic model, to change one of its equations to reflect the policy rule in question, to solve the model with this new equation, and then to compute summary statistics and counterfactual historical simulations which illustrate the effects of the change. In the context of evaluating the effect of nominal GDP targeting, this strategy was used by Taylor (1985), McCallum (1988), and Pecchenino and Rasche (1990) to evaluate various targeting rules, although the rules and/or empirical models used in these studies differed.

The empirical models we consider are a series of VAR models of the form (1). The focus here is on constructing performance bounds which measure the best outcome which the Fed could achieve were it to adopt a nominal GDP targeting strategy, relative to the performance of its historical monetary policy. As discussed in section 3, we therefore make three admittedly extreme assumptions: that the monetary instrument in question is perfectly controllable; that the Fed could adopt the GDP targeting rule which was optimal over the 1959-1992 period; and that changing the rule by which money growth is set does not change the dynamics of the rest of the system and, in particular, does not change the relationship between money and output, inflation, and interest rates. Completely satisfying these assumptions are unrealistic and one could not expect to achieve the performance bound in practice. Nonetheless, the computation of such a bound is a useful step: were the performance bound to indicate little room for improvement beyond historical Fed policy, there would be little reason to switch to a nominal GDP targeting regime.

To determine the optimal GDP targeting policy, we adopt the objective of minimizing the variance of GDP growth. It should be emphasized that this differs from the performance criterion used by McCallum (1988), who examined the deviation of the level of nominal GDP from a constant growth path of 3% per year. The key difference is that, in attempting to stabilize the growth rate rather than the level around a constant growth path, we are permitting base drift in the target. As discussed in section 1, not permitting base drift has the feature – which to us seems undesirable – of leading to a policy of inflating when nominal GDP is below its target path but is growing stably at 3% per year, and of tightening when GDP growth is stable at 3% but GDP is above its target path.

Because of lags in data availability, the Fed is unable to measure shocks to the economy as they occur. The money control rules considered here therefore set the money growth rate in the current quarter as a function of economic data through the previous quarter.[7]

The Optimal Control Rule.

The class of models we work with are VAR's of the form,

$$x_t = \beta_x + A_{xx}(L)x_{t-1} + A_{xY}(L)Y_{t-1} + A_{xm}(L)m_{t-1} + \epsilon_{xt} \tag{1a}$$

$$Y_t = \beta_Y + A_{Yx}(L)x_{t-1} + A_{YY}(L)Y_{t-1} + A_{Ym}(L)m_{t-1} + \epsilon_{Yt} \tag{1b}$$

$$m_t = \beta_m + A_{mx}(L)x_{t-1} + A_{mY}(L)Y_{t-1} + A_{mm}(L)m_{t-1} + \epsilon_{mt} \tag{1c}$$

where x_t is the growth rate of nominal GDP, Y_t denotes additional variables, such as inflation as measured by the GDP deflator, and m_t denotes the monetary variable of interest, for example the growth rate of M2. The model dynamics are summarized by the lag polynomials A(L) and the error covariance matrix, $\Sigma = E\epsilon_t\epsilon_t'$. To implement the optimal control algorithms we assume that the VAR is stable, that is, the roots of I-A(L)L all fall outside the unit circle. To simplify exposition we henceforth assume that variables enter as deviations from their means so that the intercepts can be omitted.

The rules considered in this paper are specified in terms of growth rates of money and output. These rules automatically adjust for historical shifts in the level of velocity because target money growth rates are computed from past growth rates rather than levels. These rules do, however, assume a constant mean growth of velocity. Although M2 velocity growth has had a mean of approximately zero over the 1959 - 1992 period, in principle it is desirable to permit the mean growth rate of velocity to change with interest rates, and to consider rules which adjust for persistent nonzero growth in velocity. Including a levels relation between velocity and the interest rate in (1) is a natural way to do this, and the result would be a vector error correction model. The empirical results of section 4 suggest that this error correction term (the long-run money demand residual) should enter this specification. Although the general nature of the calculations for a vector error correction model are the same as for the VAR model analyzed here, the details differ, and the analysis of the vector error correction model is beyond the scope of the investigation and is left to future research.

Let $Z_t = (x_t\ Y_t')'$, $\epsilon_{zt} = (\epsilon_{xt}\ \epsilon'_{Yt})'$, $A_{Zm}(L) = [A_{xm}(L)\ A_{YM}(L)']'$, and let $A_{ZZ}(L)$ be the matrix with (1,1) block $A_{xx}(L)$, (1,2) block $A_{xY}(L)$, (2,1) block $A_{Yx}(L)$, and (2,2) block $A_{YY}(L)$. Then (1) can be rewritten,

(2a) $$Z_t = A_{ZZ}(L)Z_{t-1} + A_{Zm}(L)m_{t-1} + \epsilon_{Zt}$$

(2b) $$m_t = A_{mZ}(L)Z_{t-1} + A_{mm}(L)m_{t-1} + \epsilon_{mt}.$$

The roots of $A_{ZZ}(L)$ are assumed to lie outside the unit circle, so that $C_{ZZ}(L) = (I - A_{ZZ}(L))^{-1}$ exists. Then (2a) can be written,

(3) $$Z_t = \Gamma(L)m_t + C_{ZZ}(L)\epsilon_{Zt}$$

where $\Gamma(L) = C_{ZZ}(L)A_{Zm}(L)$. Let $\Gamma_{xm}(L)$ denote the (1,1) element of $\Gamma(L)$ and let $C_{xZ}(L)$ denote the first row of $C_{ZZ}(L)$.

The optimal control problem is to choose the money growth rule which solves,

(4) $$\min \operatorname{var}(x_t) = \operatorname{var}[\Gamma_{xm}(L)m_{t-1} + C_{xZ}(L)\epsilon_{Zt}]$$

Because m_t is assumed to be a function of data only through the previous quarter, the solution to this problem has the form, $m_t = d(L)\epsilon_{Zt-1}$, where d(L) solves (4). The solution sets

(5) $$\Gamma_{xm}(L)m_{t-1} + C^{\dagger}_{xZ}(L)\epsilon_{Zt-2} = 0$$

where $C^{\dagger}_{xZ}(L) = \sum_{j=2}^{\infty} C_{xZ,j}L^{j-2}$, so $m_t = \Gamma_{xm}(L)^{-1}C^{\dagger}_{xZ}(L)\epsilon_{Zt-1}$ and $d(L) = \Gamma_{xm}(L)^{-1}C^{\dagger}_{xZ}(L)$.

The rule $m_t = d(L)\epsilon_{Zt-1}$ is expressed in terms of the shocks to the x_t equations (2a). In terms of implementation, it is more natural to express the rule in terms of actual historical data. This mathematically equivalent form of the rule is obtained by expressing ϵ_{Zt-1} in terms of the data using (2a). The optimal control rule thus is,

(6) $$m_{t-1} = h^{*}_{mZ}(L)Z_{t-1}$$

where $h^{*}_{mZ}(L) = [1 + d(L)A_{Zm}(L)L]^{-1}d(L)[I - A_{ZZ}(L)L]$. The controlled system is thus given by (2a) and (6).

A primary measure of the performance of the optimal rule (6) considered here is the ratio of the standard deviations of the variables when the system is controlled, relative to the standard deviation of the variables when the system is uncontrolled. To make this precise, let r_i denote the ratio of the standard deviation of the i-th variable in (1) under the optimal control rule to its standard deviation in the uncontrolled case. Let F(L) denote the moving average lag polynomial matrix of the uncontrolled system, that is, $F(L) = (I-A(L))^{-1}$, where A(L) is the matrix lag operator with elements $A_{xx}(L)$, etc. in (1). Let $F^*(L)$ denote this matrix when the system is controlled using the optimal feedback rule (6), so that $F^*(L) = [(F^*_{ZZ}(L)\ 0)'\ (F^*_{mZ}(L)\ 0)]'$, where $F^*_{ZZ}(L) = C_{ZZ}(L) + \Gamma_{Zm}(L)d(L)L$ and $F^*_{mZ}(L) = d(L)L$. Let Z^*_{it} denote the i-th variable in Z_t when the system is controlled (so that $Z^*_t = F^*_{ZZ}(L)\epsilon_{Zt}$). Finally, let e_i denote the i-th unit vector. Then the performance measure r_i is,

(7a) $$r_i = \{var(Z^*_{it})/var(Z_{it})\}^{½}$$

(7b) $$= \{e_i'\textstyle\sum_{j=1}^{\infty}F^*_j\,\Sigma_\epsilon F^{*\prime}_j e_i/e_i'\sum_{j=1}^{\infty}F_j\Sigma_\epsilon F_j'e_i\}^{½}.$$

Econometric Inference.

Because the coefficients of the VAR (1) are unknown, r_i must be estimated. A natural estimator of r_i, $\hat{r}_i$, is obtained by substituting the empirical estimates of F(L), $F^*(L)$, and Σ into (7b). However, in evaluating the distribution of r_i, two sources of uncertainty need to be addressed. The first is the conventional sampling uncertainty which arises because only estimates of the VAR parameters are available. The second source of uncertainty arises because, for any set of fixed VAR parameters, different shocks to the system will result in different realizations of Z_{it} and Z^*_{it}, so that the ratios of the sample variances computed using these shocks will differ from the population variances in (7a). Both sources of uncertainty need to be addressed in estimating the distribution of the performance measures. For example, one might wish to know the probability of realizing a decade-long sequence of shocks which have the perverse effect of making the optimal policy destabilizing relative to maintaining the status quo, that is, the probability of realizing r_i greater than one simply as a result of adverse shocks.

The statistics reported below estimate the distribution of variance reductions which would be realized over a ten year span, were the Fed to adopt the optimal policy (6). The first source of uncertainty, parameter uncertainty, can be handled by conventional means. Because r_i is a continuous function of the unknown VAR parameters and because those parameters are have a joint asymptotic normal distribution, the estimator $\hat{r}_i$ has an asymptotic normal distribution. In principle, this asymptotic distribution of can be computed using the "delta" method, although we employ a numerically more convenient technique (discussed below).

The second source of uncertainty, shock uncertainty, can be handled by considering the distribution of the sample estimator $\bar{r}_{i|A,\Sigma,h^*}$,

$$(8) \qquad \bar{r}_{i|A,\Sigma,h^*} = \{\bar{var}(Z^*_{it}|A, \Sigma, h^*)/\bar{var}(Z_{it}|A, \Sigma)\}^{1/2}$$

where $\bar{var}(Z_{it}|A, \Sigma))$ denotes the sample variance of a realization of Z_{it} of length N (say) generated from the VAR (1) with parameters A and Σ, and where $\bar{var}(Z^*_{it}|A, \Sigma, h^*)$ denotes the corresponding sample variance when Z^*_{it} is generated from the controlled system (2a) and (6) with the parameters $A_{ZZ}(L)$, $A_{Zm}(L)$, $\Sigma_{ZZ} = \epsilon_{Zt}\epsilon_{Zt}'$, and $h_{Zm}(L)$. With the additional assumption that ϵ_t is normally distributed $N(0, \Sigma)$, these parameters completely describe the uncontrolled system (1) and the controlled system (2a) and (6). Conditional on these parameters, the statistic (8) is a ratio of quadratic forms of normal random variables, and a variety of techniques are available for computing this conditional distribution. For example this can be computed by stochastic simulation, which is the approach used by Judd and Motley (1991) to estimate ranges of inflation and output growth produced under McCallum's (1988) monetary base rule (holding constant the model parameters and the control rule), and by Judd and Motley (1992) in their investigation of using interest rates as intermediate targets.

The measures of uncertainty reported in this and the next section combine the parameter and shock uncertainty arising from using the optimal rule (6). This was done using Monte Carlo methods. Specifically, in each Monte Carlo draw a pseudo-random realization of (A, Σ) was drawn from its joint asymptotic distribution; $F^*(L)$ was computed using the submatrices $A_{ZZ}(L)$ and $A_{Zm}(L)$, using the estimate of $h_{mZ}(L)$ obtained from the historical U.S. data;

pseudo-random realizations of length N were drawn from from stochastic steady states of the controlled and uncontrolled system; and the sample variance (8) was computed. The distribution of these sample variances estimates the distribution of r_i given $h^*_{mZ}(L)$.[8] Throughout, N = 40 was used, corresponding to a ten-year span.

In general the distribution of $\bar{r}_i$ is asymmetric ($\bar{r}_i$ by construction is nonnegative but can be arbitrarily large). The distribution of r_i is therefore summarized by its mean, median, and 10% and 90% percentiles. In addition, the fraction of realizations of r_i which would be expected to fall below one – that is, to indicate reduced volatility under the control rule – is also reported.

7.2 Empirical Results

The optimal control algorithm was applied to two VAR's using quarterly data over the 1959-1992 period. In both models, the optimal rule minimizes the variance of quarterly nominal GDP growth, with M2 as the instrument. The first model includes quarterly growth in GDP, quarterly inflation as measured by the GDP deflator, the quarterly growth of interest rates, and the quarterly growth of M2. This use of growth rates of interest rates, rather than their changes, differs from the specifications of sections 4 and 5. While this modification has negligible effect on the estimated distributions of the performance measures, it prevents interest rates from taking on negative values in the simulations used to compute the performance measures.

Estimated performance measures and their distributions are reported in table 9 for two systems. Because the objective is to minimize the variance of nominal GDP growth, for nominal GDP growth these ratios represent performance bounds.

First consider the system in panel A. The point estimate of r_{GDP} is .840, but the mean and median of the distribution of ten-year realizations of r_{GDP} is somewhat larger, approximately .88. The mean ratio for four-quarter growth in GDP drops to .76. While the spread of the distribution also increases, the 90% point remains approximately constant, and the fraction of realizations of r_{GDP} under one is approximately 90%. In short, over a ten year span the expected effect of the optimal GDP rule would be to reduce the standard deviation of annual GDP growth by one-fourth; in nine out of ten decade-long spans the optimal rule would result in at least some reduction in the variance of nominal GDP.

The reductions in the volatility of real GDP and GDP inflation (not shown in the table) are less than for nominal GDP. At the four-quarter horizon, the GDP targeting rule results in a mean improvement of only 6.6% for inflation and 12.6% for real GDP. However, in two-thirds of simulated decades the volatility of inflation is reduced, while in three-fourths of the decades the volatility of real GDP growth is reduced.

The main findings from this exercise are robust to using the funds rate rather than the 90-day Treasury bill rate as the financial variable. In this system, the optimal monetary policy still reduces nominal GDP volatility in 83% to 87% of the decades, depending on the horizon. The mean reductions for inflation volatility and real GDP volatility are again more modest than those of nominal GDP. However, the optimal policy results in reductions of the volatility of annual inflation and real output in, respectively, three-fifths and three-fourths of the simulated decades.

7.3 Counterfactual Historical Simulations and Interpretation

Supposing the Fed had optimally used M2 to reduce GDP volatility, how might the economy have performed over the 1959 - 1992 period? Answering this question both is of interest in its own right and provides a vehicle for illustrating the dynamic interactions in the model. Because the VAR captures the historical correlations between lagged money and future output, it is a useful framework for computing the performance bounds reported in the previous section. It is, however, arguably less well suited for performing counterfactual simulations, for several reasons. The model does not impose any restrictions implied by economic theory and thus is at a minimum inefficiently estimated; because structural shocks are not identified (in the sense of structural VAR analysis), simulated responses to shocks are difficult to interpret.

Nonetheless, the computation of counterfactual simulations sheds light on the dynamic properties of the model.

With these caveats in mind, we therefore simulate the path of nominal GDP under the optimal policy rule. The simulated path is computed using the historical shocks to the first three equations in the system, with M2 determined using the *ex-post* optimal control rule. This simulated path, computed from the system in panel A of table 9, is plotted in figure 4 along with the actual path of GDP. The optimal policy rule would have produced markedly different paths of money and interest rates, but only somewhat different paths of nominal GDP, real GDP, and inflation, relative to the actual data.

A convenient way to summarize the optimal control rule is in terms of its impulse response function to shocks to GDP, inflation, and the interest rate; this impulse response function is d(L) given following (5). The change in the log of money in response to a one-standard deviation error in each of the three equations for the other system variables is plotted in figure 5. These shocks have not been orthogonalized so the impulse responses have no ready structural interpretation. However, for a given system this impulse response facilitates the comparison of the optimal rule to the simpler rule examined in the next section.

8. Performance of Alternative M2 Growth Rules

8.1 Simpler Nominal GDP Targeting Rules

The optimal rule provides a bound by which to gauge the potential performance of alternative nominal GDP targeting schemes. As practical advice, however, the rule has some shortcomings. It involves multiple lags of several variables and thus would be rather complicated to follow. More importantly, the optimal rule depends on the specified model; because all empirical models are best thought of as approximations, as long as these approximations "fit" (for example, forecast out-of-sample) equally well, there is no compelling reason to choose the optimal rule from any one model. Thus, it is natural to wonder whether there are simpler money growth rules which would result in performance nearly as good as that achieved by the optimal rule, but which are simpler to explain and to implement and which do not hinge on any one model specification.

In this section we therefore consider alternative, simpler models for targeting nominal GDP. In doing so, we parallel the investigations of simple money growth rules by Taylor (1985), McCallum (1988), Hess, Small and Brayton (1992), and Judd and Motley (1991) and extend this work to the distribution of the performance measures r_i. The money growth rules considered here have the partial adjustment form,

$$(9) \qquad (m_t - \mu_m) = \lambda(\mu_x - x_{t-1}) + (1-\lambda)(m_{t-1} - \mu_m),$$

where μ_x is the target growth rate of nominal GDP, μ_m is the mean money growth rate, and $0 < \lambda < 1$. Thus money growth adjusts by a fraction λ when realized GDP growth in the previous quarter deviates from its target value by the amount $\mu_x - x_{t-1}$.

It was suggested in section 4 that long-run money demand is well-characterized as a cointegrating relationship between money, nominal GDP, and interest rates, with a unit income elasticity. If interest rates are I(1) with no drift (an empirically and economically plausible specification), velocity growth has mean zero. Thus μ_m is set to equal μ_x, and the rule (9) simplifies to $m_t = -\lambda x_{t-1} + (1-\lambda)m_{t-1}$. As in section 7, the rule (9) is implemented in its deviations-from-means form, so that m_t and x_t are taken to be deviations from their 1960 - 1992 averages.

The effect of the partial adjustment money growth rule (9) can be evaluated using the techniques of section 7.1. For example, the formula (7) for the performance measure r_i is as described in section 7.1, except that the rule (9) replaces the optimal rule (6). Econometric inference concerning the performance measure can also be computed using the procedure described in section 7.1.

8.2 Empirical Results

The partial adjustment rule (9) was examined on a course grid of values of λ between .1 and .5. In general, the performance measures r_i were insensitive to the choice of λ for $.2 \leq \lambda \leq .4$; within this range, no value of λ dominated in terms of variance reduction at all horizons. The results for $\lambda = .4$ are shown in table 10 for the two systems analyzed in table 9.

The striking conclusion from table 10 is that this simple partial adjustment rule produces nearly the same distributions of performance measures as does the optimal rule. The partial adjustment rule results in a somewhat lower fraction of simulated decades of improved performance for nominal GDP at the quarterly horizon – only 70%, compared with 88% under the optimal rule – but 85% of the simulated decades have reduced annual nominal GDP volatility. As is the case under the optimal rule, under the partial adjustment rule the improvements in inflation and real output variability are less than for nominal GDP. However, the partial adjustment rule still results in improvements in inflation and output in two-thirds of the simulated decades.

The results in panel B of table 10 indicate that these findings are robust to replacing the 90-day Treasury bill rate with the funds rate. Overall, according to these performance measures the simple rule comes close to achieving the reduction in nominal GDP volatility of the optimal rule and is robust to changing the interest rate used in the specification.

8.3 Counterfactual Historical Simulations and Interpretation

The fact that the simple rule provides a close approximation to the optimal rule suggests that the counterfactual historical values simulated using the partial adjustment rule will be close to the counterfactual values based on the optimal rule. This is in fact the case. The actual and simulated values of annual GDP growth for the system with the 90-day Treasury bill rate are plotted in Figure 6. A comparison of figures 4 and 6 reveals only slight differences between the historical values of output growth under the two rules; perhaps the largest difference is the decline in output in 1972 under the partial adjustment rule.

The impulse responses of the partial adjustment rule are plotted in figure 7. (These impulse responses are the lag polynomial $\partial(L)$ in the representation $m_t = \partial(L)\epsilon_{Zt}$, which is obtained by solving (2a) and (9); the plotted impulse response are scaled by the standard deviation of ϵ_{Z_it}, and so represent responses to one-standard-deviation changes in ϵ_{Zt}.) Although the simulated output and inflation paths are quite similar under the two rules, the impulse responses of the rules are quite different. Clearly the partial adjustment rule is not an approximation to the optimal rule, in the sense that its impulse response function approximates the impulse response function of the optimal rule. However, its effect on nominal output (and also on inflation and real output) is close to that of the optimal rule. A partial explanation for this is that, as was emphasized in section 4, the estimates of the short-run effect of money on output, while statistically significant, is still rather small so that rather different money growth paths can have similar, modest effects on nominal output and inflation. More generally, these results indicate that the objective function of the variance of nominal GDP is rather flat with respect to various money growth rules.[9]

9. Adjusting Monetary Policy to Consensus Forecasts

The empirical analysis in sections 7 and 8 uses a simple VAR model to derive and to evaluate policy rules. This analysis assumes that these low-dimensional models adequately capture stable historical correlations and that the remaining predictable structure in GDP is limited. If the VAR's have performed worse than alternative forecasting systems, then one would be reluctant to place much weight on them in designing or evaluating monetary policy. This section assesses the predictive performance of our simple VAR model by comparing it to professional economic forecasts: had our simple VAR models been run historically, would they have produced forecasts of nominal GDP as good as the historical professional record? McNees's (1986) comparison of *ex-ante* forecasts indicates that, at least for some economic variables, VAR's are capable of performing as well or better than conventional professional forecasting models. The VAR's examined in McNees's study have more variables and a different structure than those here, however, so that work does not directly address our models.

We therefore provide evidence on how our models would have performed over this period, relative to those of private forecasters. Of course, the main problem with such an exercise is that our models have been estimated on the full sample while the forecasters were operating in real time with all the difficulties that entails. Thus a comparison of our full-sample VAR to real-time forecasts would be quite unfair. Consequently, we examine pseudo out-of-sample forecasts from recursive regressions with the variables in our VAR's, with the initial forecast quarter ranging from 1971:1 to 1991:2. For example, the forecast of GDP growth from 1971:1 to 1972:1 is computed on the basis of a regression estimated for the period from 1960:2 to 1970:4; the 1971:2 to 1972:2 forecast is based on data for 1960:2 to 1971:1; and so forth. The systems used are those in the previous two sections, with nominal income, inflation, M2, and the 90-day Treasury bill rate; systems where M2 and then the interest rate are dropped; and a system in which oil prices are included.

The professional forecasts considered are the DRI and the ASA-NBER forecasts. The DRI forecasts are "early in quarter forecasts" released approximately 4 weeks into the first quarter of the year being forecasted. The survey date of the ASA-NBER survey varies historically but is typically between four and six weeks into the first quarter being forecasted. (The DRI and ASA-NBER professional forecasts are of four-quarter GNP and are evaluated relative to four-quarter GNP growth.) For comparison we also present the "constant" forecast in which the forecast is simply the average 4- quarter growth rate of nominal GDP over the 1971:1 to 1992:2 interval.

The RMSE's of the recursive VAR forecasts and of the professional forecasters are given in table 11. The RMSE for the DRI and ASA-NBER forecasts are very similar at 2.26. A comparison with the "constant" forecast shows that the forecasts reduce the mean square error (the square of RMSE) by approximately one third. The simple three lag recursive regression that includes lagged values of M2, real GDP and the GDP deflator (line 3 of table 11) has an

RMSE of 2.37. Adding lagged three month interest rates reduces the RMSE to 2.26, the same as the DRI and ASA/NBER forecasts. With the addition of oil prices the RMSE of the VAR forecasts is actually slightly lower than the RMSE of DRI and ASA/NBER forecasts.

The conclusion from table 11 is that the variables used in the sections 7 and 8 in fact predict nominal GDP with the same accuracy as either the median of private forecasters in the ASA-NBER survey or the forecasts issued by DRI. Of course, despite the use recursive forecasts this is not a true comparison of *ex-ante* forecasts: we have the advantage of using final rather than preliminary values of the data and have drawn on the past decade of experience with VAR's to specify our model. Also, our models are silent on one of the main features of most professionally-used models, the forecasting of the detailed components of real output. Still, the results are sufficiently encouraging to lead us to conclude that the systems simulated in sections 7 and 8 provide a plausible empirical framework for the discussion of alternative monetary policy rules.

10. The Federal Reserve's Ability to Control M2

Although the Federal Reserve announces broad annual target ranges for M2 growth, the actual growth of M2 in 1992 was below the bottom of the target range and for 1991 was at the very bottom of the range. In both years the target range was 2.5 percent to 6.5 percent; actual M2 growth was 2.7 percent in 1991 and 2.2 percent in 1992. Within both years there were substantial periods of zero or negative growth of M2.

Federal Reserve officials emphasize that they do not control M2 directly. To the extent that Fed wants to alter M2, it proceeds indirectly based on an estimated statistical relationship between M2 and the Federal funds rate. If the level of M2 projected by that relationship lies below the desired level, open market purchases could be used to lower the Federal funds rate until the projected level of M2 is satisfactory. This might of course cause a conflict between those who focus on the M2 targets and those who think in terms of the effect of changes in the

Federal funds rate on inflation and real economic activity and thus regard M2 as only a coincident indicator of nominal GDP rather than as a policy instrument that causes future changes in nominal GDP.

Such a conflict did not arise during 1991 and 1992, however, because the Federal Reserve's statistical relation persistently overestimated the level of M2 that would result from the existing Federal funds rate. Many Federal Reserve officials who wanted to see a higher level of M2 believed that M2 was about to increase more rapidly without the need for the further stimulus of a lower Federal funds rate (and the associated increase in reserves.)

The Fed's indirect and inaccurate approach to controlling M2 is currently necessary because the link between Federal Reserve policy and the M2 money stock has become very different from the standard textbook picture.[10] In the textbook world, banks must keep reserves in proportion to their liabilities, i.e., in proportion to the noncurrency portion of the stock of money. When Federal Reserve open market purchases of Treasury bills increase bank reserves, banks are automatically induced to increase the noncurrency component of the money stock in proportion to the increase in reserves.

In reality, however, banks are now required to hold reserves against only a small fraction of their liabilities. Since reserves are no longer required for time deposits and certain other liabilities, reserve requirements apply to only about 20 percent of total M2. An open market purchase of securities by the Fed automatically leads to a rise in M1 (since reserves are required for almost all of the noncurrency components of M1) but does not necessarily cause a rise in M2. In practice, the banks have responded to increases in reserves by substituting low cost M1 funds (checkable deposits) for the more expensive M2 funds (time deposits). As a result, M1 has grown very rapidly during 1991 and 1992 while M2 has grown at less than the targeted level.

It is possible that a more aggressive trial and error procedure for adjusting reserves (or the Federal funds rate) might allow the Fed to achieve its desired level of M2 within each quarter. Fed officials doubt this, however, asserting that the lag between changes in the Federal funds rate and the subsequent change in M2 is much longer than a quarter. The Fed could eventually achieve the desired M2 level by trial and error changes in reserves but could not do so in each quarter.

This problem could be avoided and the Federal Reserve could reassert control over the quarterly level of M2 if reserve requirements were expanded to all the components of M2. Throughout most of the history of the Federal Reserve System, banks were required to maintain reserves against both demand deposits and time deposits. But the ratio of reserves to deposits has been reduced since the 1970s, with the reserve requirements on personal time deposits eliminated in 1980 and on nonpersonal time deposits in 1990.

The Federal Reserve has reduced reserve requirement ratios and eliminated the reserve requirements on time deposits to eliminate the implicit tax that is otherwise levied on the banks. Because the Federal Reserve pays no interest on the funds that the banks deposit as required reserves, the reserve requirements act as a tax on bank deposits. This tax was particularly heavy in the 1970s and early 1980s when inflation caused short-term interest rates to be very high. The "reserve requirement tax" made it particularly difficult for banks to attract deposits after the creation of money market mutual funds since such funds are not subject to reserve requirements at all. More recently, the Federal Reserve reduced the reserve requirement tax as a way of temporarily increasing bank profitability at a time when banks are under pressure to increase capital.

Because the Federal Reserve is precluded by law from paying interest on reserves, it has chosen to reduce and eliminate reserve requirements as the only way to reduce the reserve requirement tax. If Congress had responded to the higher short-term interest environment of the 1970s and 1980s by permitting the Federal Reserve to pay interest on required reserves and by extending reserve requirements to personal deposits, the Fed would have been able to maintain reserve requirements on all types of bank deposits that are in M2 and would therefore be better able to control M2 directly.

Extending reserve requirements to time deposits so that all of M2 is subject to the same reserve requirement while paying interest on those additional required reserves would have no economic or financial impact as such but would give the Federal Reserve the ability to control M2 from quarter to quarter.[11] Since the banks would obtain the needed additional reserves by selling Treasury bills to the Federal Reserve, this open market operation would neutralize the otherwise contractionary macroeconomic effect of the increase in reserve requirements. If the interest rate paid on the additional reserves is the same as the Treasury bill rate, the interest that the banks would receive on the additional required reserves would just balance the interest that they would otherwise have collected on the Treasury bills that they sell to obtain those additional reserves; the banks would thus be neither better nor worse off financially as a result of the increased reserve requirements. Similarly, since the Federal Reserve would pay in interest on the additional reserves the same amount that it receives on the Treasury bills acquired through the associated open market operations, there would be no effect on the budget of the Federal Reserve and therefore no effect on the budget of the Federal government. The only effect would be to increase the ability of the Federal Reserve to control M2.

Achieving accurate control of M2 requires that the same reserve requirement apply to all of the components of M2. The Federal Reserve historically imposed substantially lower reserve requirements on time deposits than on demand deposits on the theory that the time deposits were less liquid and therefore that banks required fewer reserves for prudential and liquidity purposes. It is important to emphasize that such considerations are irrelevant in the current context. The reserve requirements must be set uniformly in order to give the Federal Reserve control over the M2 money stock and not to assure that the banks have adequate liquid reserves. Since paying interest on time deposits would mean that this increase in the reserve requirements on such accounts would have no impact on the profitability of the banks or on the budget of the government, there is no problem with having reserve requirements on time deposits that are high by historic standards. Failure to do so is likely to mean Federal Reserve inability to control quarterly changes in M2.

11. Conclusion

This paper has studied the possibility of using M2 to target the quarterly rate of growth of nominal GDP. The evidence that we present indicates that the Federal Reserve could probably guide M2 in a way that reduces not only the long-term average rate of inflation but also the variance of the annual GDP growth rate.

The statistical tests that we present show that M2 is a useful predictor of nominal GDP. We cannot reject the assumption of parameter stability over time using a variety of tests that permit the data to determine a point at which parameter changes occur.

A simple optimizing model based on a VAR reduces the mean ten-year standard deviation of annual GDP growth by over 20 percent. Although there is uncertainty about this value because of both parameter uncertainty and stochastic shocks to the economy, we estimate that the probability that the annual variance would be reduced over a ten year period exceeds 85 percent. A much simpler policy based on a single equation linking M2 and nominal GDP is shown to be almost as successful in reducing this annual GDP variance. The evidence thus contradicts those who assert that there is no stable relation between nominal GDP and M2 and those who, like Milton Friedman, have argued that the relation is so unstable in the short run that it cannot be used to reduce the variance of nominal GDP. The empirical models considered here are too simplified for us to recommend either of the rules considered as normative and quantitative prescriptions for monetary policy; at a minimum this analysis would need to be extended to handle data revisions, frequency of data availability, and additional predictive variables. We have argued, however, that our main conclusion that controlling M2 growth can result in substantial reductions in the volatility of GDP growth is robust to the details of our empirical model and policy rule.

Despite this evidence of a potentially useful link between nominal GDP and M2, there are two possible problems in implementing this strategy. First, the Federal Reserve does not currently control M2 directly. We show that the link between the monetary base, which the

Fed now controls, and nominal GDP is too weak and erratic to provide a reliable instrument for targeting nominal GDP. We explain, however, that the Federal Reserve could control quarterly M2 growth completely by extending reserve requirements to all of the components of M2.

Second, we cannot be certain that a shift of Fed policy to control M2 in this way would not change the basic reduced form parameters linking M2 and nominal GDP. We take some comfort from the fact that many changes in financial institutions and Federal Reserve procedures during our thirty year sample period did not cause significant parameter instability. These two issues cannot be resolved by empirical research. Each reader will have to decide whether they are likely to be insuperable problems. We hope not.

This research has encouraged us to extend our investigation in several ways. On a technical level, the simulations do not allow for a slowly changing mean growth of velocity which would be linked to long-run trends in interest rates. The Granger causality tests suggested that introducing this additional error-correction term (the long-run money demand residual) was empirically warranted. This leads us to speculate that replacing the VAR's in sections 7 and 8 with vector error correction models will improve the estimated performance of the money rules and will produce more meaningful simulations by tying together velocity and interest rate movements.

The objective analyzed here has been to reduce the variance of quarterly nominal GDP growth. An alternative rule with considerable appeal is one in which the objective is to minimize the expected square of the GDP gap, that is, the deviation of GDP from potential GDP. An example of this is the "hybrid" rule studied in Hall and Mankiw's contribution to this volume. An alternative objective would be to minimize the one-sided shortfall of real GDP from the estimated level of potential GDP. In either case, these alternative objectives would result in monetary policies which are more aggressive when the GDP gap is larger, in particular producing relatively more expansionary monetary policy at a cyclical trough.

Central bankers object to strict rules for controlling M2 because they do not like the increased variability of short-term interest rates which would result. An idea worth investigating would therefore be a monetary policy rule that includes short-term interest rate changes as part of the criterion function, e.g., a weighted average of the change in the nominal or real GDP growth rate and in the level of the short-term interest rate.

International experience shows that central banks prefer to define their goal as price stability rather than the control of nominal GDP. It would be interesting to examine the effects on nominal and real GDP stability of alternative monetary policy rules that sought to adjust M2 growth in a way that achieved a desired level of inflation in the medium term.

We expect to return to these important issues in a future paper.

Appendix A

Data: Definitions and Transformations

Series definitions

NGDP gross domestic product (bil.$,saar)

PGDP gross domestic product:implicit price deflator

RGDP real gross domestic product (nominal gdp/pgdp)

M2 money stock:m2(m1+o'nite rps,euro$,g/p&b/d mmmfs&sav&sm time dep(bil$,sa) (Citibase series FM2)

MBASE monetary base, adj for reserve req chgs (FRB of St. Louis)(bil$,sa) (Citibase series FMBASE)

R-90 interest rate: U.S. Treasury bills,sec mkt,3-mo.(% per ann,nsa) (Citibase series FYGM3)

R-FF interest rate: Federal funds (effective) (% per annum,nsa) (Citibase FYFF)

R-1YR interest rate: U.S. Treasury const maturities,1-yr.(% per ann,nsa) (Citibase series FYGT1)

R-10YR interest rate: U.S. Treasury const maturities,10-yr.(% per ann,nsa) (Citibase series FYGT10)

G10_G1 R-10YR minus R-1YR

CP6_G6 6-mo. commercial paper rate minus 6-mo. U.S. T-bill rate (using CITIBASE definitions, CP6_GM6 = FYCP-FYGM6)

POIL producer price index: crude petroleum (82=100,nsa) (Citibase series PW561)

ZMD error from M2 money demand cointegrating relation (unit income elasticity) as discussed in the text

All data are taken from CITIBASE. All data are quarterly. Monthly data (interest rates and money supply data) were aggregated to the quarterly level by averaging the data for the months within the quarter.

Data Transformations

Unless explicitly stated otherwise the data are used after the following transformations: NGDP, PGDP, RGDP, and POIL enter in first differences of logarithms and interest rates (R-90, R-FF) enter in first differences. There are three exceptions to this general rule. The long-run money demand cointegrating relations discussed in section 4 are specified between log velocity and the level of interest rates. Error correction terms (the money demand error ZMD and the interest rate spreads CP6_GM6 and G10_G1) enter the regressions and tests in sections 4, 5 and 6 in levels. In the VAR's in sections 7 and 8, interest rates appear in growth rates (first log differences) rather than first differences.

Appendix B

Tests for Parameter Stability

This appendix summarizes the construction and asymptotic distribution theory of the tests for parameter stability employed in sections 5 and 6. The tests apply to the standard time series regression model, modified to incorporate the possibility of nonconstant parameters:

$$\text{(A.1)} \qquad y_t = \alpha_t + \beta_t' x_t + \epsilon_t, \quad t = 1, \ldots, T,$$

where ϵ_t is a homoskedastic martingale difference sequence with variance σ^2. The k-1 stochastic regressors x_t are assumed to be mean zero and integrated of order zero (I(0)). Under the assumption that the regressors are I(0), the assumption that they have mean zero is made without loss of generality under the null, since a constant is included in the regression. (Under the alternative of changing coefficients, the transformation to mean zero regressors can always be done, but it changes the time-variation process of the intercept so the power of the tests discussed below is not invariant to demeaning the data although the asymptotic size is.) Additional technical conditions are needed to obtain formal distribution theory for these tests. These conditions are typically weak, for example that sample x_t covariance matrix is consistent for a positive definite matrix; that x_t has at least four moments; and that the partial sum process constructed from ϵ_t obeys a functional central limit theorem. Note that x_t may include lagged y_t, assuming there are no unit roots in the y_t process.

The stability tests employed in sections 5 and 6 examine the hypothesis that the parameters α and β are constant, against the alternative that they change one or more times during the sample. The tests fall into three classes: Chow-type tests for a break at a single, unknown date; CUSUM-type tests; and Nyblom's (1989) tests of time-varying parameters. These three classes of tests are described in turn.

A.1 Chow-type Break-point Tests.

These statistics test the null hypothesis, H_0: $(\alpha_t, \beta_t) = (\alpha, \beta)$, against the alternative,

(A.2) $$H_1: (\alpha_t, \beta_t) = (\alpha, \beta), t \leq k; \ = (\bar{\alpha}, \bar{\beta}), t > k,$$

where k is an unknown date, $1 \leq k \leq T$. Were k known *a-priori*, then the appropriate test statistic would be the likelihood ratio (equivalently, Wald) test of parameter constancy, that is, the Chow test, say $F_T(k)$. Because k is unknown, a natural modification would be the maximum of these, say $\max_{k \in [t_0, T-t_0]} F_T(k)$, where t_0 reflects initial and terminal values for which the test is not evaluated. This modification was proposed by Quandt (1960) and is termed the Quandt likelihood ratio (QLR) statistic. Optimal tests against the alternative (A.2) were studied by Andrews and Ploberger (1991). No uniformly most powerful test exists in this problem, even asymptotically and with normal errors, so different tests are powerful against different alternatives. Two alternative statistics they propose are the mean of the F-statistics (in general a weighted mean, which has an interpretation as an LM statistic) and an exponential average of the F-statistics, the so-called exponential Wald statistics (which is most powerful against distant local alternatives in a sense made precise in Andrews and Ploberger (1991)). The three Chow-type statistics considered here thus are,

(A.3a) $$QLR = \max_{k \in [t_0, T-t_0]} F_T(k)$$

(A.3b) $$\text{mean-Chow} = (T-2t_0)^{-1} \sum_{k=t_0}^{T-t_0} F_T(k)$$

(A.3c) $$\text{AP exp-W} = \ln\{(T-2t_0)^{-1} \sum_{k=t_0}^{T-t_0} \exp(\tfrac{1}{2} F_T(k))\}$$

Because these tests involve increasingly many single-break F statistics, conventional distribution theory cannot be used to obtain their limiting distribution. However, their limiting distribution is readily obtained by applying the functional central limit theorem and the continuous mapping theory. To obtain these limits, suppose that $t_0/T \to \lambda$ as $T \to \infty$. Let "=>" denote weak convergence on the space D[0,1]. Then (e.g. Andrews and Ploberger (1991)), under the null hypothesis,

(A.4a) $$QLR \Rightarrow \sup_{s\in[\lambda,\, 1-\lambda]} F^*(s)$$

(A.4b) $$\text{mean-Chow} \Rightarrow \int_{\lambda}^{1-\lambda} F^*(s)ds$$

(A.4c) $$\text{AP exp-W} \Rightarrow \ln\{\int_{\lambda}^{1-\lambda} \exp(\tfrac{1}{2}F^*(s))ds\}$$

where $F^*(s) = B_k(s)'B_k(s)/(s(1-s))$, where $B_k(s)$ is a k-dimensional Brownian bridge, that is, $B_k(s) = W_k(s) - W_k(1)$, where $W_k(s)$ is a standard k-dimensional Brownian motion on the unit interval. For extensions of these results to the case that some regressors are I(1), see Banerjee, Lumsdaine and Stock (1992) and Hansen (1992). The limiting representations in (A.4) facilitate the computation of the limiting distributions under the null and thus of the critical values for the tests.

A.2 CUSUM-type Tests.

An intuitively appealing test for structural breaks is the CUSUM statistic proposed by Brown, Durbin and Evans (1975). This test rejects if the time series models systematically over- or under-forecasts y_t, more precisely, if the cumulated one-step-ahead forecast errors, computed recursively, tend to be either too positive or negative. Ploberger and Kramer (1992a, 1992b) proposed a modification of this statistic which is computationally simpler because it is based on full-sample residuals rather than recursive residuals. Let e_t be the residuals from the OLS fit of (A.1), and let $S_T(k)$ denote the standardized partial sum process of these residuals, that is, $S_T(k) = (\hat{\sigma}^2 T)^{-\frac{1}{2}} \sum_{s=1}^{k} e_s$, where $\hat{\sigma}^2$ is the usual OLS estimator of σ^2. The two statistics considered here are, (A.5a) $\text{P-K max} = \max_{k \in [1,T]} |S_T(k)|$

(A.5b) $\text{P-K meansq} = T^{-1}\sum_{k=1}^{T}(S_T(k))^2$

The P-K meansq statistic was previously proposed by MacNeill (1978) as a test for parameter stability.

The limiting distribution of these statistics is readily obtained using the functional central limit theorem and the continuous mapping theorem. Because the regressors are I(0) by assumption, under the null hypothesis the residual partial sum process has the limit, $S_T(\cdot/T) \Rightarrow B_1(\cdot)$, where B_1 is a one-dimensional Brownian bridge on the unit interval. By the continuous mapping theorem, we have,

(A.5a) $\text{P-K max} = \sup_{s \in [0,1]} B_1(s)$

(A.5b) $\text{P-K meansq} = \int_0^1 (B_1(s))^2 ds,$

which can be used to obtain limiting distributions under the null.

These tests have nontrivial local asymptotic power only against shifts in the intercept term, assuming the regressors are mean zero and stationary: a shift in the coefficient β in a $T^{-½}$ neighborhood will remain asymptotically undetected, since the sample mean of x_t is consistent for zero (formal results proceed following Ploberger and Kramer (1990)).

A.3 Nyblom's (1989) Tests for Time-Varying Parameters.

A different alternative hypothesis is that the parameters of the process are stochastic and follow a random walk. Nyblom (1989) considered the more general alternative that the parameters follow a martingale, a special case of which is the single-break model (A.2), and

LM tests against the random walk alternative. He considered the case that all the parameters are time-varying, but in our application we are interested as well in testing the hypothesis that a subset of the parameters are time-varying. Let R be a q×k matrix of known constants, so that the null hypothesis is that $R[\alpha_t\ \beta_t']' = R[\alpha\ \beta']'$ and the alternative is that,

(A.6) $$H_1\colon\ R[\alpha\ \beta_t']' = \zeta_t,\ \ \zeta_t = \zeta_{t-1} + \nu_t,\ \ \nu_t \text{ i.i.d. } (0,\sigma^2)$$

where $(\nu_1, \ldots, \nu_T)$ and $(\epsilon_1, \ldots, \epsilon_T)$ are independent. It is maintained that $R^{\dagger}[\alpha_t\ \beta_t']' - R^{\dagger}[\alpha\ \beta']' = O_p(T^{-\frac{1}{2}})$, where $R^{\dagger}$ is the complement of R in $\mathbb{R}^k$. In the linear regression model (A.1) and the alternative hypothesis (A.6) with jointly normal i.i.d. errors, Nyblom's (1989) test is,

(A.7) $$L = T^{-1}\sum_{\ell=1}^{T} V_T(\ell)'(R\Sigma R')^{-1}V_T(\ell),$$

where Σ is the OLS variance-covariance matrix of (α, β) and V_T is the partial sum process, $V_T(\ell) = T^{-\frac{1}{2}}\sum_{s=1}^{\ell} e_s[1\ \ x_s']'$.

In the special case that R tests only the constancy of the intercept, because the regressors have mean zero this test is asymptotically equivalent to the P-K meansq statistic. In general, however, these tests differ. Under the null hypothesis, $\epsilon_t x_t$ is a martingale difference sequence. Thus the asymptotic null representation of the statistic is,

(A.8) $$L \Rightarrow \int_0^1 B_k(s)'B_k(s)ds.$$

For Monte Carlo results comparing these tests in the linear regression model, see Andrews, Lee and Ploberger (1992).

Footnotes

1. The Federal Reserve Board staff biannually presents to the FOMC simulations of a macroeconometric model which emphasize the direct effect of alternative interest rate levels on inflation and real economic activity (rather than through a monetary aggregate), and some members of the committee undoubtedly see their votes in these terms.

2. Specifically, the long-run interest semielasticities were estimated using the dynamic OLS procedure in Stock and Watson (1989a) with four leads and lags, with standard errors computed using an AR(2) model for the regression error. The estimated long-run interest semielasticity of M2 demand is .0061 (standard error .0020), based on the 90-day Treasury bill rate. The DOLS regression was run over 60:2 - 91:2, with the remaining observations used for initial and terminal conditions.

3. The in-sample $\bar{R}^2$'s are typically larger for the real GDP and inflation regressions (not reported here) than they are for the nominal GDP regressions. This might at first appear puzzling, since nominal GDP growth is the sum of real GDP growth and GDP inflation. However, over this period real GDP growth and inflation growth, and especially their predictable components, have been negatively correlated, that is, predictably high inflation has been associated with predictable slow real growth. For example, in a VAR(3) with real GDP, GDP inflation, M2, and R-90, the in-sample forecasts of one-quarter inflation and real GDP growth from 1960:2 - 1992:2 have a cross-correlation of -.50, while their forecast errors have a correlation of .07.

4. Friedman and Kuttner's (1992a) regression 3 in their table 1b and regression 2 in our table 1 are the most directly comparable. Both regress quarterly nominal output growth on lagged growth of nominal output and M2. Friedman and Kuttner use 4 lags over 1970:3 - 1990:4 and nominal GNP, and report an F-statistic of 2.37. Using nominal GDP rather than nominal GNP, over 1970:3-1990:4 with 4 lags this F-statistic is 2.85 (p-value .030). The p-value of the test of the hypothesis that three lags of both M2 and GDP are adequate is .69. Using 3 lags

and nominal GDP, 1970:3 - 1990:4, the Granger causality statistic is 3.87 (p-value .012). Using the 1970:3 - 1992:2 sample, with 4 lags it is 3.39 (p-value .013; the test of 3 vs. 4 lags for M2 and GDP has a p-value of .71) and with 3 lags it is 4.80 (p-value .004), the value in our table 1, regression 2. The remaining differences presumably are accounted for by their use of GNP rather than GDP and by data revisions.

5. In contrast to the general lack of rejections in table 4, there is more evidence of instability in comparable equations which forecast real GDP. The evidence of instability is quite strong when GDP inflation is the dependent variable: at least one test rejects at the 5% level in 10 of the 12 regressions involving M2. The estimated break dates occur early in the sample, most commonly 67:2 and 71:1.

6. The cointegrating residuals ZMD in the regressions in table 6 and 7 are based on long-run monetary base and M1 demand relations, respectively, estimated using the 90-day Treasury bill rate, using the same estimation procedure as applied to the M2 cointegrating vector as discussed in section 4. The interest semielasticities are .0503 (.0172) for base money and .0737 (.0304) for M1. The evidence that the monetary base system is cointegrated is weak, however, so the F-statistics involving ZMD for the base should be interpreted cautiously; this term is included for the base for comparability to the results for M1 and M2. We suspect that these F-statistics overstate the predictive content of the base; see Ljungqvist, Park, Stock and Watson (1988).

7. The choice of a one-quarter lag in the money growth rules represents an attempt to incorporate realistic lags in data availability. Many important series are available monthly with no lag or lags of at most eight weeks; these include interest rates, employment and unemployment, industrial production, and personal income. However, other key series are available with lags exceeding one quarter. In particular, advance GDP estimates are not available until four weeks after the end of the quarter, and revised estimates are available later yet, so that the availability lag for GDP is at least one quarter plus four weeks, arguably longer. The one-quarter availability lag used here represents a compromise among these various true availability lags.

8. Technically, to compute the conditional distribution we would need to draw A(L) from the conditional distribution of A(L) given $h^*_{mZ}(L)$, where $h^*_{mZ}(L)$ is given by the expression following (6). Instead, A(L) was drawn from its unconditional distribution. Sampling from the conditional distribution with these nonlinear restrictions would be computationally prohibitive and is beyond the scope of this investigation.

9. It does not follow that *any* money growth rule results in modest improvements. For example, letting $m_t = .4x_t + .6m_{t-1}$ (so that money growth *increases* when nominal output is above its target) is destabilizing and results in a point estimate of 4-quarter r_{GDP} of 1.70.

10. For an earlier discussion of this subject, see Feldstein (1991, 1992).

11. This point is developed in Feldstein (1991).

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Table 1
Predictive Content of M2

Dependent Variable: Nominal GDP Growth

Estimation period: quarterly, 1960:2 to 1992:2

Eq.	Regressors	$\bar{R}^2$	$\bar{R}^2(2)$	$\bar{R}^2(4)$	F-tests (p-values) on lags of: M2	R-90	R-FF	G10_G1	CP6_G6
1	NGDP	0.101	0.105	0.073					
2	NGDP M2	0.228	0.293	0.285	7.88 (0.000)				
3	NGDP M2 R-90	0.272	0.284	0.279	8.67 (0.000)	3.43 (0.019)			
4	NGDP M2 R-FF	0.277	0.294	0.288	5.11 (0.002)		3.77 (0.013)		
5	NGDP M2 R-90 R-FF	0.302	0.318	0.282	6.12 (0.001)	2.38 (0.074)	2.70 (0.049)		
6	NGDP M2 R-90 ZMD	0.317	0.344	0.328	7.57 (0.000)	2.90 (0.038)			
7	NGDP PGDP	0.094	0.113	0.092					
8	NGDP PGDP M2	0.221	0.295	0.326	7.60 (0.000)				
9	NGDP PGDP R-FF	0.199	0.195	0.174			6.30 (0.001)		
10	NGDP PGDP R-90	0.166	0.151	0.161		4.48 (0.005)			
11	NGDP PGDP M2 R-90	0.271	0.286	0.310	6.76 (0.000)	3.77 (0.013)			
12	NGDP PGDP M2 R-FF	0.277	0.294	0.316	5.31 (0.002)		4.10 (0.008)		
13	NGDP PGDP M2 R-90 ZMD	0.334	0.375	0.388	8.54 (0.000)	3.20 (0.026)			
14	NGDP PGDP M2 R-90 POIL ZMD	0.324	0.371	0.378	8.61 (0.000)	2.88 (0.039)			
15	NGDP PGDP R-90 CP6_G6	0.224	0.249	0.176		3.00 (0.034)			3.99 (0.010)
16	NGDP PGDP M2 R-90 CP6_G6 ZMD	0.356	0.413	0.378	6.92 (0.000)	3.09 (0.030)			2.27 (0.084)
17	NGDP PGDP R-90 G10_G1	0.195	0.194	0.192		2.09 (0.106)		2.43 (0.089)	
18	NGDP PGDP M2 R-90 G10_G1 ZMD	0.355	0.400	0.386	8.23 (0.000)	3.64 (0.015)		2.25 (0.086)	

Notes: $\bar{R}^2$, $\bar{R}^2(2)$, and $\bar{R}^2(4)$ are respectively the $\bar{R}^2$'s from regressions of one-, two-, and four-quarter growth of the dependent variable onto a constant and three lags of the listed regressors. Data sources and transformations are given in appendix A. The F-statistics (p-values in parentheses) test the restriction that coefficients on the indicated regressors are zero. In the regressions including the money demand cointegrating residual ZMD, the F-statistics on M2 include the test of this restriction.

Table 2
Predictive Content of M2

Dependent Variable: Real GDP Growth

Estimation period: quarterly, 1960:2 to 1992:2

Eq.	Regressors	$\bar{R}^2$	$\bar{R}^2(2)$	$\bar{R}^2(4)$	- - - F-tests (p-values) on lags of: - - - M2	R-90	R-FF	G10_G1	CP6_G6
1	RGDP	0.013	0.009	0.033					
2	RGDP M2	0.150	0.203	0.260	7.69				
					(0.000)				
3	RGDP M2 R-90	0.175	0.186	0.258	5.96	2.25			
					(0.001)	(0.086)			
4	RGDP M2 R-FF	0.182	0.204	0.270	4.95		2.62		
					(0.003)		(0.054)		
5	RGDP M2 R-90 R-FF	0.203	0.212	0.253	5.61	2.01	2.36		
					(0.001)	(0.117)	(0.075)		
6	RGDP M2 R-90 ZMD	0.254	0.283	0.321	8.34	1.67			
					(0.000)	(0.176)			
7	NGDP PGDP	0.118	0.182	0.196					
8	NGDP PGDP M2	0.265	0.359	0.426	9.15				
					(0.000)				
9	NGDP PGDP R-FF	0.235	0.316	0.382			7.22		
							(0.000)		
10	NGDP PGDP R-90	0.193	0.246	0.339		4.77			
						(0.004)			
11	NGDP PGDP M2 R-90	0.290	0.352	0.437	6.46	2.40			
					(0.000)	(0.071)			
12	NGDP PGDP M2 R-FF	0.304	0.384	0.463	4.97		3.24		
					(0.003)		(0.025)		
13	NGDP PGDP M2 R-90 ZMD	0.329	0.400	0.457	7.03	1.97			
					(0.000)	(0.122)			
14	NGDP PGDP M2 R-90 POIL ZMD	0.313	0.391	0.444	6.97	1.90			
					(0.000)	(0.134)			
15	NGDP PGDP R-90 CP6_G6	0.290	0.396	0.383		2.29			6.42
						(0.082)			(0.000)
16	NGDP PGDP M2 R-90 CP6_G6 ZMD	0.383	0.486	0.468	5.37	1.70			4.35
					(0.001)	(0.171)			(0.006)
17	NGDP PGDP R-90 G10_G1	0.235	0.304	0.384		1.64		3.21	
						(0.184)		(0.026)	
18	NGDP PGDP M2 R-90 G10_G1 ZMD	0.359	0.438	0.469	6.60	2.58		2.82	
					(0.000)	(0.057)		(0.042)	

Notes: see the notes to table 1.

Table 3
Predictive Content of M2

Dependent Variable: Nominal GDP Growth

Estimation period: quarterly, 1970:3 to 1992:2

					--- F-tests (p-values) on lags of: ---				
Eq.	Regressors	$\bar{R}^2$	$\bar{R}^2(2)$	$\bar{R}^2(4)$	M2	R-90	R-FF	G10_G1	CP6_G6
1	NGDP	0.075	0.088	0.082					
2	NGDP M2	0.186	0.247	0.250	4.80 (0.004)				
3	NGDP M2 R-90	0.229	0.226	0.231	3.60 (0.017)	2.51 (0.065)			
4	NGDP M2 R-FF	0.232	0.238	0.239	2.86 (0.042)		2.61 (0.057)		
5	NGDP M2 R-90 R-FF	0.238	0.229	0.223	3.48 (0.020)	1.21 (0.312)	1.30 (0.280)		
6	NGDP M2 R-90 ZMD	0.246	0.256	0.251	3.46 (0.012)	1.98 (0.124)			
7	NGDP PGDP	0.057	0.091	0.079					
8	NGDP PGDP M2	0.159	0.233	0.271	4.25 (0.008)				
9	NGDP PGDP R-FF	0.156	0.179	0.171			4.17 (0.009)		
10	NGDP PGDP R-90	0.135	0.156	0.183		3.42 (0.021)			
11	NGDP PGDP M2 R-90	0.206	0.213	0.256	3.31 (0.024)	2.54 (0.063)			
12	NGDP PGDP M2 R-FF	0.209	0.224	0.261	2.75 (0.049)		2.68 (0.053)		
13	NGDP PGDP M2 R-90 ZMD	0.246	0.311	0.368	3.87 (0.007)	1.74 (0.167)			
14	NGDP PGDP M2 R-90 POIL ZMD	0.224	0.298	0.342	3.89 (0.007)	1.60 (0.196)			
15	NGDP PGDP R-90 CP6_G6	0.171	0.205	0.169		2.17 (0.099)			2.12 (0.105)
16	NGDP PGDP M2 R-90 CP6_G6 ZMD	0.269	0.346	0.347	3.51 (0.011)	1.36 (0.263)			1.77 (0.161)
17	NGDP PGDP R-90 G10_G1	0.172	0.233	0.248		1.65 (0.185)		2.18 (0.097)	
18	NGDP PGDP M2 R-90 G10_G1 ZMD	0.286	0.359	0.365	3.98 (0.006)	2.43 (0.072)		2.38 (0.077)	

Notes: ZMD was computed using the full-sample estimated cointegrating vector.
See the notes to table 1.

Table 4
Tests for Structural Breaks and Time-Varying Parameters with M2

Dependent Variable: Nominal GDP Growth

Estimation period: quarterly, 1960:2 to 1992:2

Eq.	Regressors	QLR	Mean-Chow	AP Exp-W	$\hat{k}$	Chow	P-K max	P-K meansq	L-all	L-fin
1	NGDP	6.53	3.01	1.66	80:3	3.74	0.57	0.11	0.58	
2	NGDP M2	13.92	7.96	4.70	80:3	7.49	1.03	0.21	0.82	0.42
3	NGDP M2 R-90	22.93	9.63	7.56	80:3	12.41	0.72	0.18	0.99	0.58
4	NGDP M2 R-FF	19.03	9.43	6.50	80:3	9.13	1.41**	0.82**	0.84	0.47
5	NGDP M2 R-90 R-FF	33.16**	12.92	12.17*	80:3	22.01*	0.53	0.04	1.28	0.85
6	NGDP M2 R-90 ZMD	26.28	10.84	9.11	80:3	13.24	1.74**	0.95**	1.20	0.78
7	NGDP PGDP	17.46	6.48	5.17	75:2	8.60	1.69**	0.83**	1.08	
8	NGDP PGDP M2	24.46	11.99	8.97	81:1	14.94	1.17*	0.21	1.31	0.42
9	NGDP PGDP R-FF	18.17	7.62	5.41	81:3	8.75	0.92	0.18	1.04	0.12
10	NGDP PGDP R-90	16.51	8.91	5.81	81:3	11.97	1.32**	0.36*	1.11	0.16
11	NGDP PGDP M2 R-90	29.28*	12.82	11.16	80:4	20.01	1.56**	0.66**	1.43	0.60
12	NGDP PGDP M2 R-FF	26.53	12.77	10.12	81:1	15.48	0.48	0.07	1.27	0.46
13	NGDP PGDP M2 R-90 ZMD	28.78	14.54	11.16	80:4	19.95	0.85	0.14	1.52	0.64
14	NGDP PGDP M2 R-90 POIL ZMD	33.51	17.41	13.34	80:4	21.97	0.87	0.17	1.55	0.44
15	NGDP PGDP R-90 CP6_G6	27.11	13.78	10.80	73:2	15.73	1.42**	0.63**	1.79	0.65
16	NGDP PGDP M2 R-90 CP6_G6 ZMD	35.82*	20.15	15.27*	73:2	23.05	1.44**	0.59**	1.91	0.77
17	NGDP PGDP R-90 G10_G1	25.64	18.70	10.75	80:1	25.07**	0.60	0.13	2.18	0.82
18	NGDP PGDP M2 R-90 G10_G1 ZMD	29.51	17.98	11.87	75:2	21.78	1.29**	0.42*	1.78	0.82

Notes: significant at the *10%; **5%; ***1% level. The fixed-date Chow test ("Chow") has a break date of 1979:3. Because this break date is arguably data-dependent, as discussed in the text the critical values for this statistic are difficult to ascertain and the reported significance levels for this statistic (based on the standard F distribution) are at best a rough guide.

Table 5
Predictive Content of Monetary Base

Dependent Variable: Nominal GDP Growth

Estimation period: quarterly, 1960:2 to 1992:2

Eq.	Regressors	$\bar{R}^2$	$\bar{R}^2(2)$	$\bar{R}^2(4)$	F-tests (p-values) on lags of: BASE	R-90	R-FF	G10_G1	CP6_G6
1	NGDP BASE	0.169	0.168	0.167	4.45				
					(0.005)				
2	NGDP BASE R-90	0.199	0.192	0.169	2.46	2.49			
					(0.066)	(0.064)			
3	NGDP BASE R-FF	0.222	0.233	0.208	1.94		3.76		
					(0.126)		(0.013)		
4	NGDP BASE R-90 R-FF	0.244	0.250	0.198	2.69	2.12	3.35		
					(0.050)	(0.101)	(0.021)		
5	NGDP PGDP BASE	0.153	0.160	0.159	3.85				
					(0.011)				
6	NGDP PGDP BASE R-90	0.185	0.181	0.182	1.93	2.52			
					(0.129)	(0.062)			
7	NGDP PGDP BASE R-FF	0.208	0.219	0.198	1.45		3.70		
					(0.233)		(0.014)		
8	NGDP PGDP BASE R-90 ZMD	0.178	0.175	0.175	1.44	2.50			
					(0.226)	(0.063)			
9	NGDP PGDP BASE R-90 POIL ZMD	0.160	0.162	0.155	1.45	2.43			
					(0.222)	(0.069)			
10	NGDP PGDP BASE R-90 CP6_G6 ZMD	0.227	0.267	0.187	1.12	2.34			3.46
					(0.352)	(0.077)			(0.019)
11	NGDP PGDP BASE R-90 G10_G1 ZMD	0.191	0.195	0.183	0.86	1.65		1.61	
					(0.492)	(0.142)		(0.190)	

Notes: See the notes to table 1.

Table 6
Predictive Content of M1

Dependent Variable: Nominal GDP Growth

Estimation period: quarterly, 1960:2 to 1992:2

Eq.	Regressors	$\bar{R}^2$	$\bar{R}^2(2)$	$\bar{R}^2(4)$	- - - F-tests (p-values) on lags of: - - - M1	R-90	R-FF	G10_G1	CP6_G6
1	NGDP M1	0.152	0.166	0.098	3.50				
					(0.018)				
2	NGDP M1 R-90	0.185	0.167	0.132	1.75	2.67			
					(0.161)	(0.051)			
3	NGDP M1 R-FF	0.204	0.208	0.154	1.00		3.68		
					(0.397)		(0.014)		
4	NGDP M1 R-90 R-FF	0.229	0.230	0.144	1.91	2.29	3.27		
					(0.131)	(0.082)	(0.024)		
5	NGDP M1 R-90 ZMD	0.185	0.172	0.138	1.55	2.73			
					(0.191)	(0.047)			
6	NGDP PGDP M1	0.140	0.164	0.111	3.17				
					(0.027)				
7	NGDP PGDP M1 R-90	0.176	0.181	0.145	1.49	2.73			
					(0.220)	(0.047)			
8	NGDP PGDP M1 R-FF	0.194	0.199	0.161	0.78		3.66		
					(0.507)		(0.014)		
9	NGDP PGDP M1 R-90 ZMD	0.181	0.177	0.166	1.57	2.90			
					(0.168)	(0.038)			
10	NGDP PGDP M1 R-90 POIL ZMD	0.170	0.174	0.148	1.80	2.49			
					(0.134)	(0.064)			
11	NGDP PGDP M1 R-90 CP6_G6 ZMD	0.219	0.252	0.173	0.80	2.82			2.85
					(0.525)	(0.042)			(0.041)
12	NGDP PGDP M1 R-90 G10_G1 ZMD	0.194	0.199	0.169	0.98	2.39		1.61	
					(0.421)	(0.073)		(0.191)	

Notes: See the notes to table 1.

Table 7
Tests for Structural Breaks and Time-Varying Parameters with Monetary Base

Dependent Variable: Nominal GDP Growth

Estimation period: quarterly, 1960:2 to 1992:2

Eq.	Regressors	QLR	Mean-Chow	AP Exp-W	$\hat{k}$	Chow	P-K max	P-K meansq	L-all	L-fin
1	NGDP BASE	32.20***	18.62***	13.46***	81:2	29.65***	1.58**	0.75**	2.42***	1.11**
2	NGDP BASE R-90	34.40***	18.81***	14.07***	80:4	30.53***	0.50	0.05	2.37*	1.16
3	NGDP BASE R-FF	34.02***	18.25**	14.09***	81:1	28.77***	1.75**	1.10**	2.19	0.96
4	NGDP BASE R-90 R-FF	41.78***	20.99**	17.30***	80:3	35.09***	0.67	0.09	2.48	1.34
5	NGDP PGDP BASE	43.00***	24.27***	17.64***	75:2	36.60***	0.98	0.22	2.83**	0.95*
6	NGDP PGDP BASE R-90	39.17***	23.70***	16.60***	80:4	35.73***	1.47**	0.61**	2.66	1.02
7	NGDP PGDP BASE R-FF	36.93**	22.61***	15.74***	81:1	32.57***	1.66**	1.06**	2.44	0.88
8	NGDP PGDP BASE R-90 ZMD	51.21***	28.34***	21.59***	80:4	43.57***	0.86	0.27	2.86	1.20
9	NGDP PGDP BASE R-90 POIL ZMD	52.47***	30.87***	22.24***	80:4	44.17***	2.02**	1.32**	2.91	0.53
10	NGDP PGDP BASE R-90 CP6_G6 ZMD	60.42***	30.60***	26.13***	80:4	44.92***	1.46**	0.99**	3.09	1.53
11	NGDP PGDP BASE R-90 G10_G1 ZMD	51.53***	32.53***	22.75***	80:4	48.46***	1.66**	1.41**	3.17	1.63

Notes: significant at the *10%; **5%; ***1% level. See the notes to table 4.

Table 8

Tests for Structural Breaks and Time-Varying Parameters with M1

Dependent Variable: Nominal GDP Growth

Estimation period: quarterly, 1960:2 to 1992:2

Eq.	Regressors						QLR	Mean-Chow	AP Exp-W	$\hat{k}$	Chow	P-K max	P-K meansq	L-all	L-fin
1	NGDP	M1					31.76***	15.81***	12.35***	81:4	23.58***	0.60	0.08	1.53	0.74
2	NGDP	M1	R-90				35.83***	17.07**	14.46***	80:3	30.92***	1.73**	0.82**	1.62	0.89
3	NGDP	M1	R-FF				36.20***	15.85**	14.47***	81:4	26.84***	0.98	0.35*	1.41	0.88
4	NGDP	M1	R-90	R-FF			45.86***	19.08**	18.53***	80:3	37.78***	1.62**	1.55**	1.91	1.22
5	NGDP	M1	R-90	ZMD			51.22***	23.58***	21.34***	80:3	41.23***	1.84**	1.41**	2.31	1.34
6	NGDP	PGDP	M1				35.69***	19.73***	14.45***	75:2	29.16***	2.05**	1.65**	1.90	0.54
7	NGDP	PGDP	M1	R-90			39.71***	20.15**	15.96***	81:3	33.92***	1.81**	0.79**	1.89	0.65
8	NGDP	PGDP	M1	R-FF			40.66***	18.85*	16.14***	81:3	28.04**	0.56	0.07	1.68	0.51
9	NGDP	PGDP	M1	R-90	ZMD		50.44***	28.90***	21.87***	80:3	44.58***	0.73	0.12	2.90	1.21
10	NGDP	PGDP	M1	R-90	POIL	ZMD	50.78***	30.82***	21.95***	80:4	44.85***	0.98	0.27	2.99	1.01
11	NGDP	PGDP	M1	R-90	CP6_G6	ZMD	49.49***	28.90***	20.98***	81:3	39.88***	2.23**	1.67**	2.88	1.38
12	NGDP	PGDP	M1	R-90	G10_G1	ZMD	51.23***	31.03***	22.07***	81:3	43.37***	0.99	0.31	3.04	1.45

Notes: significant at the *10%; **5%; ***1% level. See the notes to table 4.

Table 9
Estimated Performance Under Optimal GDP Targetting Rule

Ratio of standard deviations of quarterly, semiannual, and annual growth rates or changes, controlled vs. uncontrolled system, over a ten-year span

Variable	Agg'n	$\hat{r}$	mean	Std.Dev.	median	10% pt	90% pt	Fract<1
A. Y = (GDP, PGDP, R-90); control = M2								
GDP	1	0.840	0.881	0.109	0.887	0.752	1.010	0.88
	2	0.762	0.824	0.147	0.824	0.644	1.001	0.90
	4	0.668	0.761	0.202	0.748	0.519	1.019	0.89
B. Y = (NGDP, PGDP, R-FF); control = M2								
GDP	1	0.851	0.900	0.115	0.903	0.762	1.034	0.83
	2	0.788	0.855	0.151	0.852	0.677	1.041	0.84
	4	0.699	0.788	0.205	0.774	0.542	1.039	0.87

Notes: The entry in the third column is the estimated reduction in the standard deviation of the variable given in the first column, temporally aggregated over the number of quarters given in the second column, were the system controlled using the optimal controller derived for the indicated control variable. The remaining columns summarize the distribution of the sample realizations of r_i over a ten-year span were the optimal rule, computed using the 1960-92 data, implemented in the future; these distributions incorporate both parameter and shock uncertainty, as discussed in the text. Data transformations are as given in the appendix. Estimation period: 1960:2 - 1992:2. Based on 2000 Monte Carlo replications.

Table 10
Estimated Performance Under Partial Adjustment GDP Targetting Rule

Ratio of standard deviations of quarterly, semiannual, and annual growth rates or changes, controlled vs. uncontrolled system, over a ten-year span

Variable	Agg'n	$\hat{r}$	mean	Std.Dev.	median	10% pt	90% pt	Fract<1
A. Y = (GDP, PGDP, R-90); control = M2								
GDP	1	0.882	0.932	0.124	0.933	0.780	1.083	0.70
	2	0.818	0.901	0.173	0.899	0.686	1.122	0.73
	4	0.659	0.779	0.213	0.762	0.527	1.060	0.85
B. Y = (NGDP, PGDP, R-FF); control = M2								
GDP	1	0.881	0.923	0.112	0.928	0.789	1.051	0.77
	2	0.818	0.890	0.156	0.889	0.698	1.079	0.77
	4	0.683	0.790	0.199	0.777	0.549	1.043	0.87

Notes: Ratios of standard deviations were computed using the partial adjustment nominal GDP targetting rule, $m_t = -\lambda x_{t-1} + (1-\lambda)m_{t-1}$ where $\lambda =$ .4, as discussed in the text. See the notes to table 9.

Table 11

RMSE's of Forecast of Four-Quarter Growth in Nominal Output, 1971:1 to 1991:2

Forecasting system	RMSE
Constant only - 71:2 - 91:2 sample:	2.76
Recursive Time Series Forecasts:	
1. Constant	2.89
2. VAR(3): RGDP, PGDP	2.68
3. VAR(3): RGDP, PGDP, FM2	2.37
4. VAR(3): RGDP, PGDP, FM2, FYGM3	2.26
5. VAR(3): RGDP, PGDP, FM2, FYGM3, POIL	2.20
Professional Forecasts:	
6. DRI, 4-quarter	2.27
7. ASSA/NBER, 4-quarter	2.26

Notes: All RMSE's refer to annual forecasts made from 1971:1 to 1991:2. For the time series models, the forecasts are of nominal GDP growth, computed using recursive regression with three lags of the indicated variable. For example, the forecast of GDP growth from 71:1 to 72:1 in model 2 was computed by regressing $\ln(GDP_t/GDP_{t-4})$ onto $(1, z_{t-4}, z_{t-5}, z_{t-6})$, where z_t is quarterly real GDP growth and quarterly inflation in quarter t, with a regression period of 1960:2 - 1970:4 with earlier observations for initial conditions; for the 71:2 forecast, the regressions were reestimated using data through 71:1, etc. The DRI and ASA/NBER forecasts are of 4-quarter GNP and are evaluated relative to 4-quarter GNP growth. The entry in the first line uses as the forecast the average 4-quarter growth rate of nominal GDP over 71:1 - 91:2, so this RMSE is $\sqrt{(n-1)/n}$ times the standard deviation of four-quarter output growth over 71:1 - 91:2.

Figure 1.
Four-quarter growth of (a) M2 (dashed line) and nominal GDP (solid line); (b) M2 and GDP inflation; and (c) M2 and real GDP, 1960 - 1992.

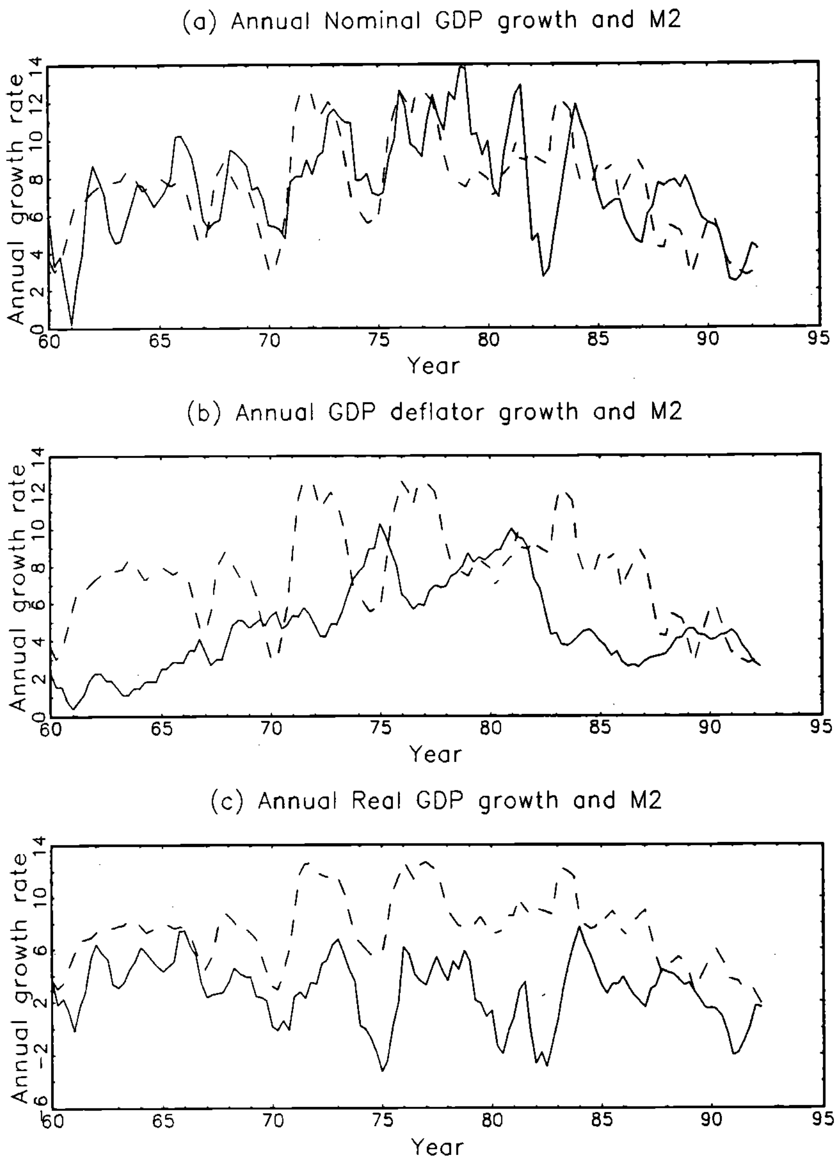


Figure 2.
Four-quarter growth of (a) the monetary base (dashed line) and nominal GDP (solid line); (b) monetary base and GDP inflation; and (c) monetary base and real GDP, 1960 - 1992.

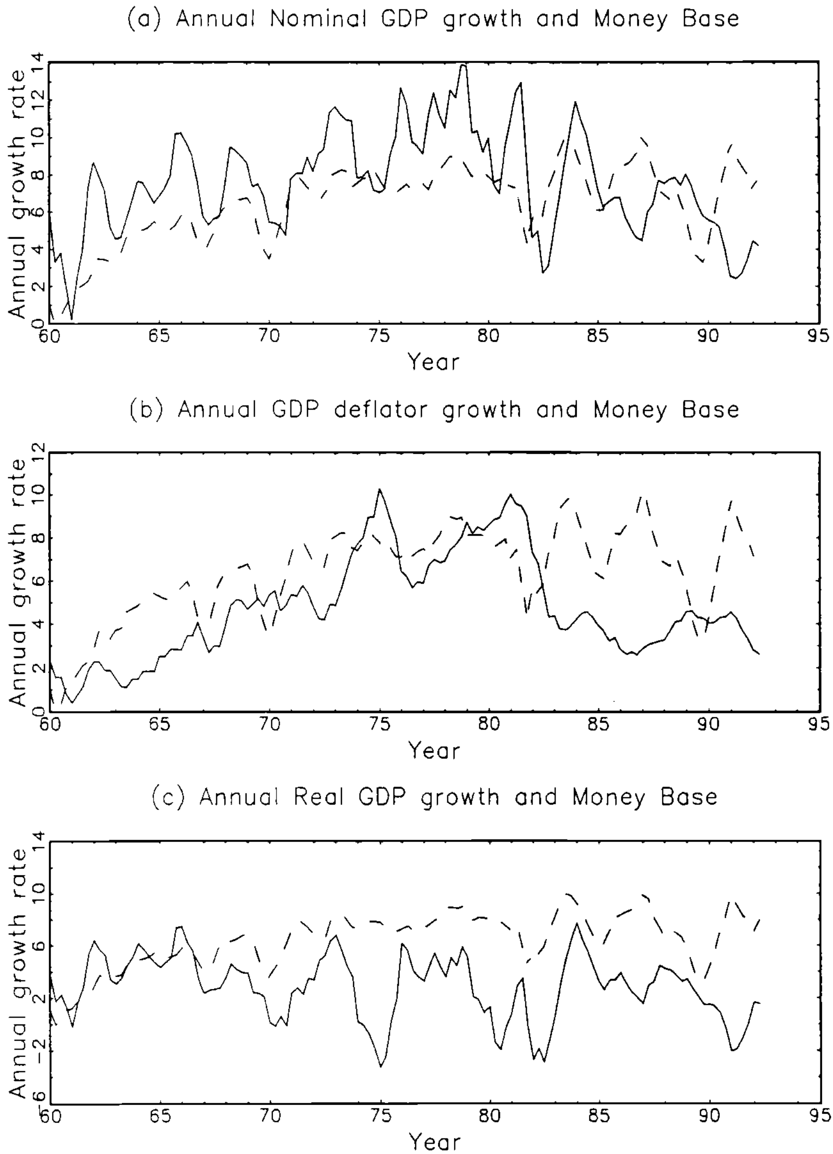
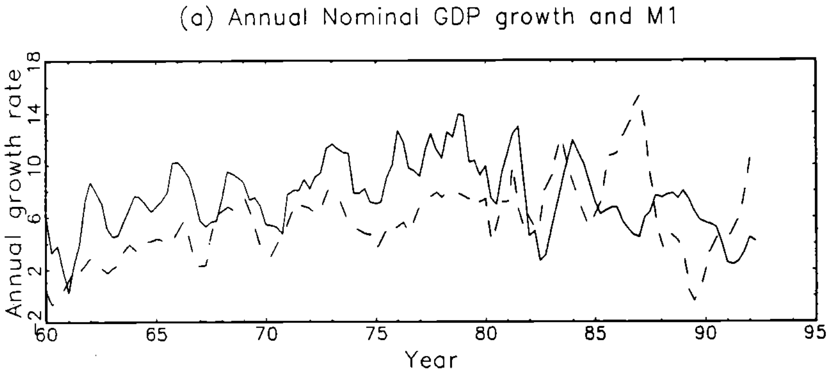
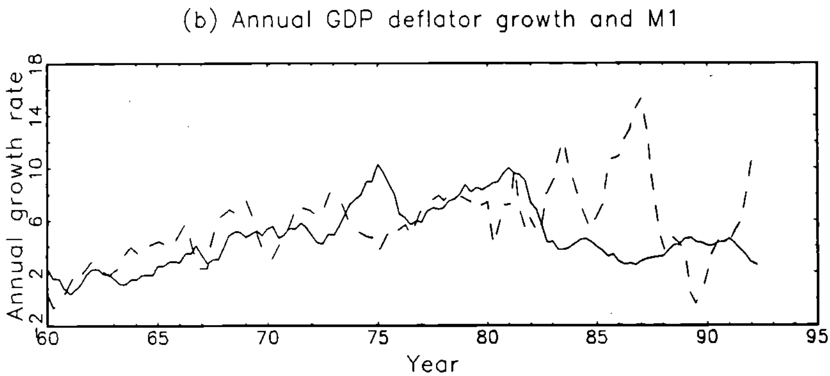
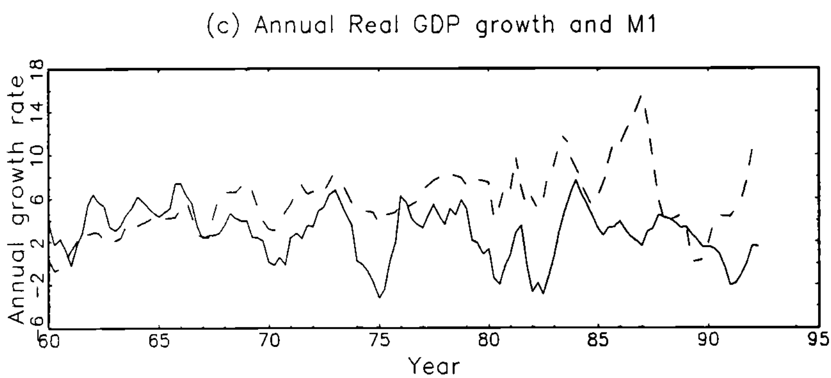


Figure 3.
Four-quarter growth of (a) M1 (dashed line) and nominal GDP (solid line); (b) M1 and GDP inflation; and (c) M1 and real GDP, 1960 - 1992.







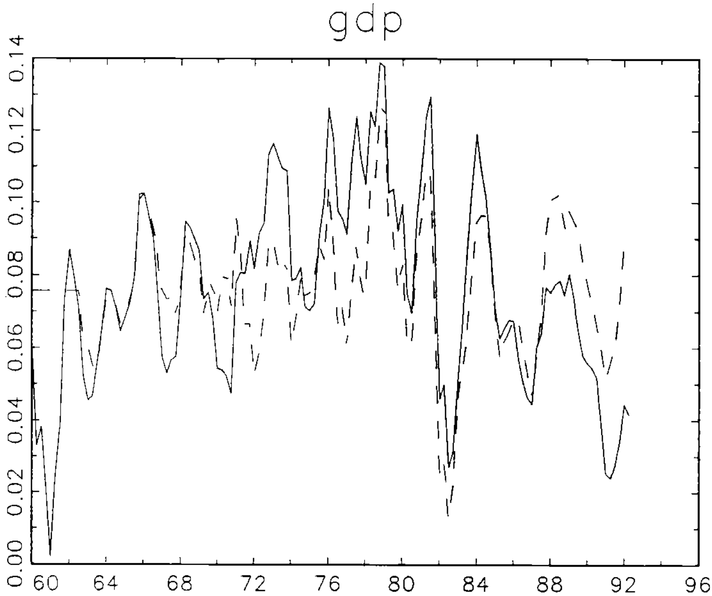


Figure 4

Actual and simulated historical values of four-quarter growth of nominal GDP: Optimal nominal GDP targeting rule, 1960 - 1992

Actual: solid line; simulation: dashed line

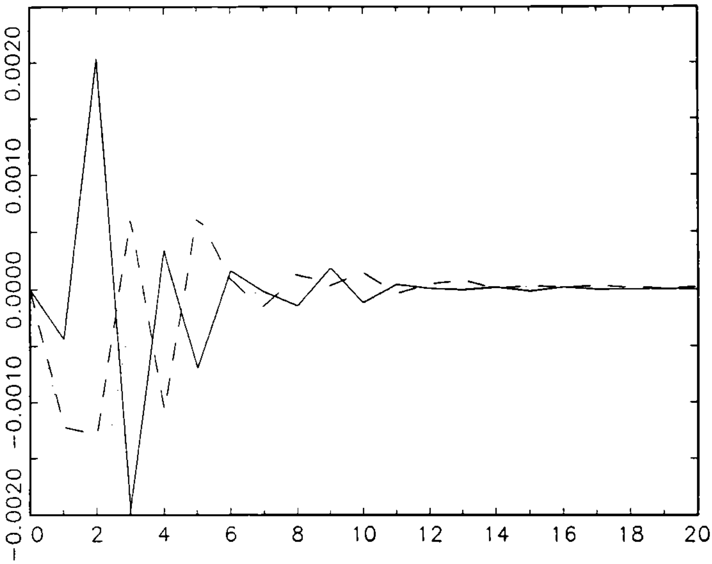


Figure 5

Impulse response functions: Optimal GDP targeting rule

Response of money growth after k quarters, relative to its mean,
to a one-standard-deviation shock in the equations for:
nominal GDP (solid line); GDP inflation (dashed line); the interest rate (dotted line)

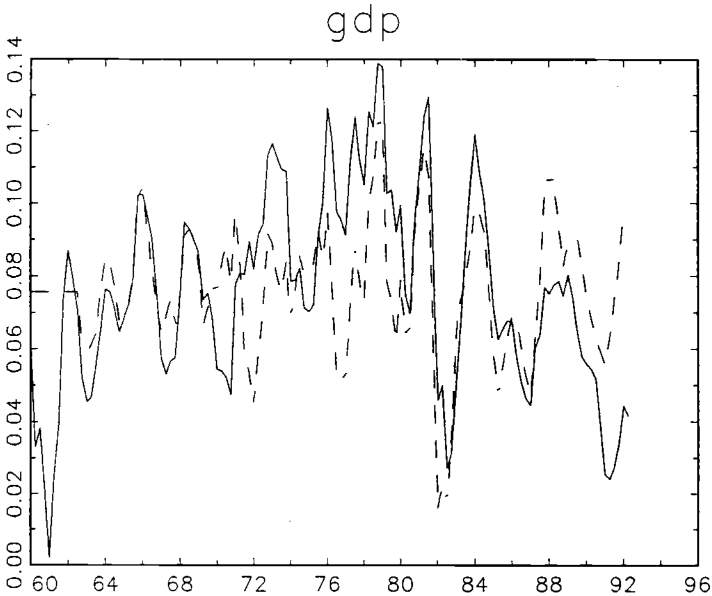


Figure 6

Actual and simulated historical values of four-quarter growth of nominal GDP: Partial-adjustment GDP targeting rule, 1960 - 1992

Actual: solid line; simulation: dashed line

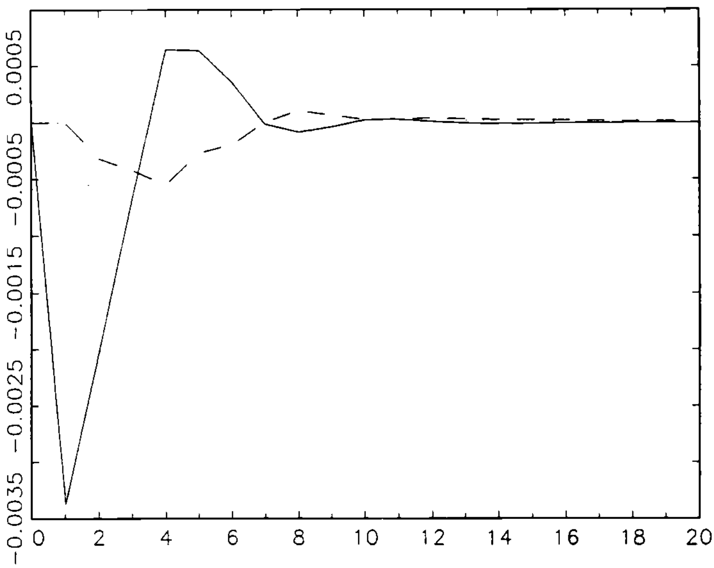


Figure 7

Impulse response functions: Partial-adjustment GDP targeting rule

Response of money growth after k quarters, relative to its mean,
to a one-standard-deviation shock in the equations for:
nominal GDP (solid line); GDP inflation (dashed line); the interest rate (dotted line)