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Money Targeting and Interest-Rate Targeting in an Uncertain World

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Introduction

Each central bank needs to provide the economy with a nominal anchor for which it is responsible. There are three basic ways of fulfilling this task: monetary targeting, interest-rate targeting, or exchange-rate targeting. Of these three options, exchange-rate targeting means that the anchoring takes place on foreign soil. Currently, no worldwide arrangement of fixed exchange rates is under discussion, and in the North American region, the United States is so much larger than both Canada and Mexico that those countries may tie their currencies to the dollar. But the United States cannot anchor the dollar to the currency of one of its North American trading partners.

The Federal Reserve, therefore, has to choose between the two domestic methods of providing a nominal anchor to the economy: monetary targeting or interest-rate targeting. An omniscient central bank would be indifferent, because the methods are equivalent in terms of resource costs. A realistic central bank has to compare the informational requirements of both methods to decide which will work best in an uncertain world. The types of uncertainty that most affect the economy are crucial here, not because one method can react more flexibly to unforeseen developments, but because different economic surprises have different effects on the degree to which the central bank can attain its targets—depending on whether interest rates or monetary aggregates are used as intermediate targets and indicators of monetary policy.

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Economic analysis of the central bank's problem requires a model that describes (a) how inflationary expectations are formed and (b) how the central bank, through steering a monetary aggregate or an interest rate, can influence future price levels or rates of inflation. The basic relations needed for a simple model of monetary policy are, therefore, a demand-for-money schedule and the definition of the real rate of interest as the difference between the nominal rate and the expected rate of inflation. These two relations will be embedded in a stochastic structure that allows for transitory and permanent shocks to the real rate of interest, the income velocity of money, and the rate of monetary expansion.

In the second section of the paper, I describe one such model, that of Robert Barro (1989). His model allows for a limited number of shocks, postulates fully flexible prices, and implies that interest-rate targeting has benefits (and no costs) over money targeting. In the third section, I develop an alternative model that is similar to Barro's but has some degree of sluggishness in prices and a richer menu of stochastic shocks. In the fourth section, I perform stochastic simulations of the different models. Solving the so-called Riccati equations associated with the systems of equations gives a measure of success in conducting monetary policy that is conditional on the choice of instrument and on the importance of the different types of shocks.[1] Analytical solutions of Riccati equations are generally not feasible, so the results in the paper will be numerical and will depend on the inputs: the interest-rate elasticity of the demand for money, as well as the size and importance of a variety of shocks to money demand, money supply, and real interest rates.

The principal result of the simulations is that interest-rate targeting becomes inferior to monetary targeting as soon as the assumption of price flexibility is abandoned. Barro's results are seen to be quite model-specific. For a variety of assumptions regarding the importance of different types of shocks to the economy, I find that monetary targeting results in superior steering of the rate of inflation over time.

Barro's Model of Interest-Rate Targeting

There are three equations in Barro's (1989) model:

$$(1)\quad i_t = p^e_{t+1} - p_t + r_t + v_t$$

[1]Results also depend on the numerical value of the interest elasticity of the demand for money, but uncertainty regarding this number is much less troublesome than is often assumed, as long as the appropriate forecasting techniques are used.

(The nominal interest rate equals the real rate, r_t, plus the expected rate of price change between this period and the next, $p^e_{t+1} - p_t$ plus an observation error, v_t.)

$$(2)\ M_t - p_t = \alpha_t - \beta i_t + \omega_t$$

(The demand for money equals an intercept, α_t, a term in the interest rate, βi_t, and a residual, ω_t.)

$$(3)\ i_t = i_{t-1} + u_t$$

(The central bank targets the nominal interest rate, shifting its target from period to period in random fashion.)

Barro shows in the context of his model that interest-rate targeting is always superior to monetary targeting. The central bank can target nominal interest rates as intensely as it wishes without endangering its control of the price level. There is no tradeoff between the two: Interest targeting is a free good.

This remarkable result depends on the following four strong assumptions. First, the current price level can adjust one-to-one to any current differences between the expected rate of growth in the money supply and the actual rate of growth of the money supply.[2] Second, the demand for money function contains just a single opportunity cost variable: the administered interest rate. The real rate of return implied in this administered interest rate is equal to the real rate of return that is exogenously given to the economy.

Third, the authorities manage to convey to the public in each period a signal of the intended growth of the nominal money supply between this period and the next. The public receives this signal without any type of noise and with full credibility in the central bank's intentions. Hence, the expected rate of inflation between this period and the next can be influenced by the authorities through variations in the expected rate of growth of the nominal money supply.[3]

Fourth, Barro evaluates monetary targeting and interest-rate targeting according to their success in minimizing the discrepancies between expected and actual price levels. This approach is consistent with his assumption that prices are perfectly flexible. However, if one takes another view of price stickiness, one would want to

[2]This assumption contrasts with the position in Barro (1983, p. 102) that the lag between changes in money and consequent changes in the price level takes up to four years.

[3]Barro views the expected rate of inflation as the difference between the actual price level this year and the expected value of next year's price level, rather than as some underlying, sluggish variable that is embedded in temporary and permanent shocks to the price level.

compute the unconditional variance of the price level or the rate of inflation.

Given these four assumptions, the results in Barro's paper follow and do not depend on the relative importance and size of the various shock terms.

The assumption that a single interest-rate variable in the money demand function is appropriate for theoretical analysis of interest-rate targeting versus the targeting of a monetary aggregate has been common to the academic literature on this topic. Bennett McCallum (1981, p. 323) remarks: "Most analyses of the instrument problem have been conducted in models with only one interest rate." He argues that introduction of a second opportunity cost variable is not useful if one closes the model with a relation that connects these interest rates. In that case, any discrepancies between the administered and the market interest rate(s) would be "random and uninteresting."

McCallum's argument shows that he also assumes maximum flexibility of the price level. Only on that assumption would an arbitrary setting of the administered interest rate be followed immediately by all market interest rates. Under these extreme assumptions, the authorities can steer the evolution of the sum of the real rate of interest and the expected rate of inflation through their manipulation of the single relevant interest rate. If we use the common assumption in this type of literature that the real rate of interest is given for the analysis, the degree of accuracy with which the authorities are able to estimate the real rate will then determine the degree of accuracy in delivering a desired path for the price level.[4]

Monetary Policy in an Uncertain World

Karl Brunner and Allan Meltzer (1989) have always maintained that at least two rates of return on financial or physical assets are required for proper analysis of monetary policy, including the evaluation of interest-rate targeting versus money-supply targeting. Some essential features of such a two-interest-rate model are preserved in the following system of equations:

(4) $i_1 = r + \Delta p^e + \sigma_t(r)$

[4]If the real rate is not given and is, in fact, irrelevant because the model is limited to a feedback rule for the nominal interest rate and a money demand schedule, the price level may become undetermined as in the classical article by Thomas Sargent and Neil Wallace (1975).

(The long-term interest rate, i_l, is equal to the real rate, r, plus the expected rate of inflation, Δp^e, plus a temporary error of observation, $\sigma_t(r)$.)

(5) $i_s = r + \Delta p^e + A$

(The short-term interest rate, i, equals the long-term rate except the observation error plus or minus a term, A, which represents the current movement in the short-term rate to equilibrate the demand for money with its supply.)

(6) $p = p^e + \sigma_t(p)$

(The current price level, p, equals the expected price level, p^e, plus a random distributed error, $\sigma_t(p)$.)

(7) $M - p = m - \epsilon i_l - \eta i_s + \sigma_t(m)$

(The demand for real balances depends on an intercept, m, the long-term interest rate, the short-term interest rate, and a residual error, $\sigma_t(m)$.)

The dynamics of this simple system in which the rate of real output, y, has been omitted as nonessential, are governed by the following assumptions:

- The real rate of interest and the intercept in the demand for money equation are subject to permanent shocks in each period (as in Barro's model).
- The intercept in the demand for money schedule is subject also to permanent shifts in its rate of growth (in other words, the trend in velocity is stochastic and has to be deduced from observations on money and prices).
- Only the short-term interest rate can adjust to equilibrate the supply and demand for money.

In this alternative model, the actual price level is simply equal to the expected price level plus or minus a random observation error. This setup is obviously at variance with most theoretical analyses of interest-rate targeting, including Barro's, in which the current price level does adjust to current monetary shocks but conforms to the analysis in James MacKinnon and Ross Milbourne (1988), who document the dangers of using results from the money demand literature to mechanically derive price adjustment equations. Their paper convincingly shows that standard stories used to justify particular dynamics in the demand for money, such as the buffer stock approach, fail to provide explanations for the much longer lags between money growth and inflation.

The alternative model can be used both to simulate money targeting and to study interest-rate targeting. Under an interest-rate rule, the adjustment needed to equate money supplied to money demanded in the current period is carried out by the money supply, which will differ from its expected value. Under monetary targeting, an opportunity cost variable has to adjust. Because all surprises within the current period have to do with temporary shocks, there is no need for the long-term interest rate to adjust. At the short end, the term A in equation (5) is available to equilibrate demand and supply of money (recall that the real rate of interest is exogenous, both in Barro's model and in the alternative model).

The degree of uncertainty about the expected rate of inflation, Δp^e, is now a function of the 10 variances that govern the dynamics of this alternative system. We shall look both at the conditional variance that measures the forecast errors in predicting inflation, and at the unconditional variance that indicates how far inflation will typically deviate from a constant path. Academic research on interest-rate targeting versus monetary targeting has concentrated on the conditional variance that can be computed analytically and has often neglected the unconditional variance that needs to be computed from the backward Riccati equation for each set of assumptions about the uncertain shocks that influence the economy.

The list of differences between Barro's model and the alternative model is presented in Table 1.

Simulation Results

In the simulations, values are inserted for the variances of the shock terms in the models that are derived from econometric computations using U.S. data. Some additional simulations use alternative values to see how sensitive the relative success of interest-rate targeting and money targeting are to these variance terms.

Uncertainties Regarding the Price Level[5]

I have estimated a univariate Kalman filter model for the logarithm of the U.S. GNP deflator over the 1948–88 period. The filter produces optimal estimates of the variances of the temporary and permanent shocks to the price level, and of the variance of the changes to the trend, respectively:

$$\sigma_t(p) = 0.414 * 10^{-4}$$
$$\sigma_p(p) = 0.0132 * 10^{-4}$$

[5]These estimates are not applicable to Barro's model.

TABLE 1

DIFFERENCES BETWEEN BARRO'S MODEL AND THE ALTERNATIVE MODEL

Barro's Model	Alternative Model
1. Price level adjusts to shocks within the current period.	1. Short-term interest rate or money supply adjusts to current shocks.
2. Public receives money supply data without error.	2. All money growth numbers are noisy.
3. Inflation is defined as the difference between today's price level and the expected price level for next year.	3. Inflation is defined as underlying ("permanent") growth rate of the price index.
4. Success is measured by forecast errors in the price level.	4. Success is measured by the stability of the price level.
5. No stochastic trend is in velocity.	5. Stochastic trend is in velocity of money.
6. A single administered interest rate is in the demand for money; real rate computed from this interest rate equals "the" real interest rate.	6. Two interest rates are in the demand for money; real rate computed from the administered rate may differ from "true" real rate.

$$\sigma_{tr}(p) = 3.087 * 10^{-4}$$

$$\text{RMSE} = 0.022;\ \rho(1) = 0.304;\ Q(5) = 23.178;$$
$$H(12) = 4.85;\ N = 0.266.$$

RMSE refers to the one-period-ahead forecast errors of the Kalman filter, $\rho(1)$ to the first-order coefficient of serial correlation of these errors, $Q(5)$ to the Box-Pierce test for serial correlation, H to the test for heteroskedasticity from A. C. Harvey (1989, p. 259), and N to a test for normality of the one-period-ahead forecast errors of the Kalman filter (see Harvey 1989, p. 260). I shall use the estimated variance of the temporary shocks as a measure of the temporary observation errors in the price level in the alternative model.

Uncertainties Regarding the Money Supply[6]

Univariate models for the U.S. money supply M1 and M2 for the 1948–88 period resulted in the following values:

[6]Ibid.

$$\sigma_t(M1) = 0.0374 * 10^{-4}$$
$$\sigma_p(M1) = 5.198 * 10^{-4}$$
$$\sigma_{tr}(M1) = 0.456 * 10^{-4}$$
$$\text{RMSE} = 0.026;\ \rho(1) = 0.044;\ Q(5) = 5.045;\ H(12) = 2.981;\ N = 1.842.$$

$$\sigma_t(M2) = 0.0118 * 10^{-4}$$
$$\sigma_p(M2) = 7.534 * 10^{-4}$$
$$\sigma_{tr}(M2) = 0.506 * 10^{-4}$$
$$\text{RMSE} = 0.029;\ \rho(1) = 0.280;\ Q(5) = 6.728;\ H(12) = 1.944;\ N = 1.122.$$

Here and below, the three variances again refer to the temporary and permanent shocks to the level and to the increments in the stochastic trend, respectively.

In order not to deviate too much from Barro's model, which does not incorporate any uncertainty about rates of growth, I have assumed that the planned rate of growth of money is observed without error by the economic agents. Later, an experiment will be performed that does include uncertainty about the expected rate of growth of money.

Uncertainties Regarding the Intercept in the Demand for Money Schedule (Shocks to Velocity)

I have estimated a single-equation Kalman filter model for U.S. M1 and M2, regressing the inverse of velocity on a stochastic intercept and on the logarithm of the long-term government bond rate (see Bomhoff 1991). Results are as follows:

M1:
$$\sigma_t(m) = 0.021 * 10^{-4}$$
$$\sigma_p(m) = 13.970 * 10^{-4}$$
$$\sigma_{tr}(m) = 0.0113 * 10^{-4}$$
$$\text{RMSE} = 0.035;\ \rho(1) = 0.338;\ Q(5) = 5.353;\ H(12) = 4.547;\ N = 2.742.$$

M2:
$$\sigma_t(m) = 0.224 * 10^{-4}$$
$$\sigma_p(m) = 0.104 * 10^{-4}$$
$$\sigma_{tr}(m) = 16.828 * 10^{-4}$$
$$\text{RMSE} = 0.040;\ \rho(1) = 0.009;\ Q(5) = 9.651;\ H(12) = 2.823;\ N = 0.899.$$

Note that Barro allows only for shocks to the level of velocity, whereas the alternative model also has changes to the trend in the income velocity of money.[7]

[7]For a thorough analysis of the evidence in favor of a stochastic trend in velocity, see Bordo and Jonung (1987).

Uncertainties Regarding the Real Rate of Interest

When I used the computed values for the expected rate of inflation from the model for the price level, subtraction from the long-term U.S. government bond rate produced a time series for the real rate of interest to which a second Kalman filter was applied as follows:

$$\sigma_t(r) = 0.0045 * 10^{-6}$$
$$\sigma_p(r) = 2.0151 * 10^{-4}$$
$$\sigma_{tr}(r) = 0.0016 * 10^{-4}$$

$$\text{RMSE} = 0.014; \rho(1) = 0.346; Q(5) = 10.123;$$
$$H(12) = 31.215; N = 12.194.$$

The variances for the shocks to the price level, the money supply, and the real rate of interest having been computed from univariate models, these numbers should be regarded as upper bounds rather than optimal estimates. Improved estimation of these variances is a topic for future research.

The solutions to the models assume that agents are aware of the relative importance of the disturbances to velocity, money, and real interest rates. The solutions agree on the specification of the model, including the numerical value of the interest-rate elasticity of the demand for money. The interest elasticity has been set at 0.043 for M1 and 0.049 for M2, both on the basis of the Kalman filter estimates for the velocity function.

Numerical solution of the forward Riccati equations for the Kalman filter system results in equilibrium values for the variances of the state variables in Barro's model.[8] Since the expected price level is one of the state variables, this procedure answers a question traditionally posed in the theoretical literature on money targeting versus interest-rate targeting: How do the conditional forecasts of the price level compare under various regimes? However, this way of formulating the problem makes sense only if the path of the expected price level and the expected rate of inflation are of no concern. If they are, one would have to compute the variation in the price level around some desired path.

[8]Barro makes two simplications to his model so he can use the method of undetermined coefficients to produce an analytic solution: First, the real rate of interest is observed without error at a one-year delay, and second, any permanent shifts to the demand for money are also known precisely with a one-year delay. Even though such simplifications are not needed in the Kalman filter approach, I have incorporated them in order to perform simulations that are fully applicable to Barro's analysis.

The first lines in both Table 2 and Table 3 relate to the conditional variance of the current price level under interest-rate targeting or money targeting. They show that forecast errors of the price level in Barro's model do not depend on whether the authorities follow a money rule or an interest-rate rule. This finding confirms Barro's principal result that interest-rate targeting delivers control over interest rates with no cost in the form of higher forecast errors in inflation.

TABLE 2

FORECAST ERRORS IN BARRO'S MODEL

M1	Interest-Rate Targeting	Money Targeting
$\text{Var}(p_t - E_{t-1}p_t)$	$14.38 * 10^{-4}$	$14.38 * 10^{-4}$
Min [var $E_{t-1}p_t$]	$28.36 * 10^{-4}$	$28.36 * 10^{-4}$
Min [var $E_{t-1}p_t$ + varΔi_t]	$52.56 * 10^{-4}$	$52.56 * 10^{-4}$
(of which var($E_{t-1}p_t$)	$32.51 * 10^{-4}$	$32.51 * 10^{-4}$)
M2	**Interest-Rate Targeting**	**Money Targeting**
$\text{Var}(p_t - E_{t-1}p_t)$	$0.52 * 10^{-4}$	$0.52 * 10^{-4}$
Min [var $E_{t-1}p_t$]	$0.63 * 10^{-4}$	$0.63 * 10^{-4}$
Min [var $E_{t-1}p_t$ + varΔi_t]	$2.62 * 10^{-4}$	$2.62 * 10^{-4}$
(of which var($E_{t-1}p_t$)	$0.66 * 10^{-4}$	$0.66 * 10^{-4}$)

TABLE 3

FORECAST ERRORS IN THE EXTENDED KALMAN FILTER MODEL

M1	Interest-Rate Targeting	Money Targeting
$\text{Var}(p_t - E_{t-1}p_t)$	$0.80 * 10^{-4}$	$0.46 * 10^{-4}$
Min [var $E_{t-1}p_t$]	$38.79 * 10^{-4}$	$38.79 * 10^{-4}$
Min [var $E_{t-1}p_t$ + varΔi_t]	$51.36 * 10^{-4}$	$51.36 * 10^{-4}$
(of which var($E_{t-1}p_t$)	$44.50 * 10^{-4}$	$44.50 * 10^{-4}$)
M2	**Interest-Rate Targeting**	**Money Targeting**
$\text{Var}(p_t - E_{t-1}p_t)$	$0.80 * 10^{-4}$	$0.55 * 10^{-4}$
Min [var $E_{t-1}p_t$]	$32.55 * 10^{-4}$	$32.55 * 10^{-4}$
Min [var $E_{t-1}p_t$ + varΔi_t]	$95.21 * 10^{-4}$	$95.21 * 10^{-4}$
(of which var($E_{t-1}p_t$)	$46.29 * 10^{-4}$	$46.29 * 10^{-4}$)

The remaining lines in Tables 2 and 3 refer to unconditional variances under different monetary policy arrangements. In other words, the numbers indicate the average (squared) error margins if one tried to maintain the indicated variable(s) on some predetermined path. These second moments do not depend on the choice between targeting the money supply and letting the interest rate absorb shocks to the demand for money, or setting an interest rate instrument and allowing the money supply to equilibrate the money market. The rule setting the desired (expected) rate of growth in money is identical for M1 and M2. That rule depends only on the state update equations of the Kalman filter and on the cost-objective function that is being minimized by the central bank.

If the authorities are interested only in stabilizing the price level, seeking formally

$$(8)\quad Min\ E\{\frac{1}{2}\sum_{t=0}^{\infty}(p^e_t)^2\},$$

the resulting optimal rule for the expected growth of money becomes

$$(9)\quad \Delta M^e_{t+1} = -p^e_{t+1}.$$

Simulation results are shown in lines 2 of Table 2.

In my alternative model, the optimal policy rule will be

$$(10)\quad \Delta M^e_{t+1} = -p^e_{t+1} - \Delta p^e_{t+1}.$$

Results are shown in lines 2 of Table 3.

If the central bank is also concerned about changes in interest rates and seeks the following policy objective

$$(11)\quad Min\ E\ \{\frac{1}{2}\sum_{t=0}^{\infty}((p^e_t)^2 + B\ (\Delta i_t)^2)\}$$

with

$$(12)\quad \Delta i_t = \Delta\ (r_t + p^e_{t+1} - p^e_t)$$

with B a constant indicating the relative importance of price-level stabilization and interest-rate smoothing, the optimal policy rule in Barro's model for the arbitrary choice $B = 1$ will be

$$(13)\quad \Delta M^e_{t+1} = -0.2496\ p^e_{t+1} - 0.2309\ p^e_t.$$

Results are shown in lines 3 of Table 2.[9] The last lines of Table 2 show to what extent the steering of the price level becomes less accurate if the central bank is concerned also with interest-rate smoothing.

In my model, the optimal rule for the value $B = 1$ becomes

$$(14)\ \Delta M^{e}_{t+1} = -0.4805\ p^{e}_{t+1} - 0.7691\ \Delta p^{e}_{t+1}.$$

Results are shown in Table 3, with the bottom lines indicating the deterioration in the quality of the price-level stabilization.

Barro makes his case for interest-rate targeting through proving that keeping the sole (administered) interest rate on a predetermined path does not cause a deterioration in the forecast errors of inflation, given the assumptions of his model. Tables 2 and 3 show how the *steering* of inflation, as opposed to its *forecasting*, does suffer if one tries to minimize changes in an interest rate as well. Interest-rate targeting is no longer a free good, if we consider the unconditional rather than the conditional variance of the price level.

Tables 4 and 5 show the effects of changes in some variance terms on the computed uncertainties in the price level. In the standard simulation, monetary targeting is more attractive than interest-rate targeting if one considers the conditional variances. As far as the unconditional variances are concerned, the relevant point is the difference between lines 2 and 3, which indicate the cost if one wishes to steer the price level and smooth interest rates at the same time. In the standard simulation, the unconditional variance of the price level increases by half if the authorities intend to smooth interest rates.

Columns 2 through 5 of Tables 4 and 5 show results for four alternative simulations: Column 2 adds uncertainty about the expected rate of growth of the money supply according to the estimated models for U.S. M1 and M2, column 3 increases the uncertainty about the permanent shifts in the real rate of interest by a factor of four, and columns 4 and 5 give results for models with greater uncertainty about the trend in the intercept of the demand for money function (the trend in velocity). Note that in all cases the assumption that the central bank is interested in interest-rate smoothing has a cost in the form of greater discrepancies between planned and actual paths of the price level.

[9]Because real rates of interest are assumed to be nonstationary in Barro's model, it is not feasible to try to control both the path of both the price level (or the rate of inflation) and the interest rate. Hence, the closest control-theoretic substitute to Barro's analysis of forecast errors is to minimize some combination of the squared deviations from a given *path* for the price level and the squared forecast errors in interest rates.

TABLE 4

GREATER UNCERTAINTY IN THE EXTENDED MODEL

	Interest-Rate Targeting				
	(1)	(2)	(3)	(4)	(5)
Var$(p_t - E_{t-1}p_t)$	0.80	0.80	0.80	0.80	0.80
Min [var $E_{t-1}p_t$]	38.79	40.61	39.15	38.82	39.90
Min [var $E_{t-1}p_t$ + varΔi_t]	51.36	54.73	58.52	52.51	57.20
(of which var$(E_{t-1}p_t)$	44.50	46.60	44.60	44.56	46.38)
	Money Targeting				
	(1)	(2)	(3)	(4)	(5)
Var$(p_t - E_{t-1}p_t)$	0.46	0.46	0.46	0.46	0.46
Min [var $E_{t-1}p_t$]	38.79	40.61	39.15	38.82	39.90
Min [var $E_{t-1}p_t$ + varΔi_t]	51.36	54.73	58.52	52.51	57.20
(of which var$(E_{t-1}p_t)$	44.50	46.60	44.60	44.56	46.38)

(1) Standard solution.
(2) Added: $\sigma_{tr}(M) = 0.456 * 10^{-4}$.
(3) Change: $\sigma_p(r)$ multiplied by 4 to give $8.060 * 10^{-4}$.
(4) Change: $\sigma_{tr}(m)$ multiplied by 4 to give 0.0452.
(5) Change: $\sigma_{tr}(m)$ multiplied by 100 to give 1.13.
NOTE: All entries must be multiplied by 10^{-4}.

TABLE 5

GREATER UNCERTAINTY IN THE EXTENDED MODEL (M2)

	Interest-Rate Targeting				
	(1)	(2)	(3)	(4)	(5)
Var($p_t - E_{t-1}p_t$)	0.80	0.80	0.80	0.80	0.80
Min [var $E_{t-1}p_t$]	32.55	32.58	32.67	83.04	1698.5
Min [var $E_{t-1}p_t$ + varΔi_t]	95.21	97.85	101.41	313.84	7309.9
(of which var($E_{t-1}p_t$)	46.29	48.62	46.42	131.16	2846.85
	Money Targeting				
	(1)	(2)	(3)	(4)	(5)
Var($p_t - E_{t-1}p_t$)	0.55	0.55	0.56	0.55	0.55
Min [var $E_{t-1}p_t$]	32.55	32.58	32.67	83.04	1698.5
Min [var $E_{t-1}p_t$ + varΔi_t]	95.21	97.85	101.41	313.84	7309.9
(of which var($E_{t-1}p_t$)	46.29	48.62	46.42	131.16	2846.85

(1) Standard solution.
(2) Added: $\sigma_{tr}(M) = 0.506 * 10^{-4}$.
(3) Change: $\sigma_p(r)$ multiplied by 4 to give $8.060 * 10^{-4}$.
(4) Change: $\sigma_{tr}(m)$ multiplied by 4 to give $67.312 * 10^{-4}$.
(5) Change: $\sigma_{tr}(m)$ multiplied by 100 to give $1682.79 * 10^{-4}$.
NOTE: All entries must be multiplied by 10^{-4}.

Conclusion

This paper uses models of money demand and money supply to investigate the differences between monetary targeting and interest-rate targeting. The main finding is that one needs to differentiate between two meanings of the term interest-rate targeting. In his influential paper, Barro (1989) used the term both to indicate the choice of an interest rate as instrument of monetary control and to refer to a central bank objective that does include the smoothing of interest rates. In my paper, I separate the two different meanings of interest-rate targeting both in Barro's own model and in an alternative model that allows for a richer menu of shocks to the economy and for less-than-perfect flexibility in the national price level.

In models that allow for a wider variety of shocks than Barro's model, his specific result that the conditional variance of the price level does not depend on whether an interest-rate target or a monetary aggregate target is used will no longer hold. More important, however, are the results, both in Barro's model and in the alternative model for the unconditional variances of the price level. If *expected* rates of price change also carry a social cost, then the central bank cannot limit itself to minimizing forecast errors in inflation, as in Barro's paper.

Neither in Barro's model nor in my alternative model is it the case that the central bank can add interest-rate smoothing to its objective function without paying a cost in terms of lower accuracy in its price-level policies. There are significant differences in the degree of control, depending on whether the central bank minimizes

$$(15)\quad Min\ E\{\frac{1}{2}\sum_{t=0}^{\infty}(p^e{}_t)^2\}$$

or

$$(16)\quad Min\ E\{\frac{1}{2}\sum_{t=0}^{\infty}((p^e{}_t)^2 + B\,(\Delta i_t)^2)\}$$

with B as a constant. This result holds, irrespective of whether a monetary aggregate or an interest rate is used as the short-term instrument of monetary control. Hence, it appears that analysis of monetary policy should distinguish between "interest-rate targeting," in the sense of using an interest rate as the short-run policy instrument, and "interest-rate smoothing," meaning the incorporation of some function of interest rates in the objective function. The former may be attractive depending on the information structure of the economy, but it does not follow that the latter—smoothing of interest rates—

can be achieved without paying the cost of less success in the central bank's prime task: the stabilization of the price level.

References

Barro, Robert J. "United States Inflation and the Choice of Monetary Standard." In *Inflation: Causes and Effects*, pp. 99–110. Edited by Robert E. Hall. Chicago: University of Chicago Press for the NBER, 1983.

Barro, Robert J. "Interest Rate Targeting." *Journal of Monetary Economics* 23 (January 1989): 3–30.

Bomhoff, Eduard J. "Stability of Velocity in the Major Industrial Countries: A Kalman Filter Approach." *IMF Staff Papers* 38 (September 1991): 626–42.

Bordo, Michael D., and Jonung, Lars. *The Long-Run Behavior of the Velocity of Circulation*. New York: Cambridge University Press, 1987.

Brunner, Karl, and Meltzer, Allan H. *Monetary Economics*. Oxford: Basil Blackwell, 1989.

Harvey, Andrew C. *Forecasting, Structural Time Series Models, and the Kalman Filter*. New York: Cambridge University Press, 1989.

MacKinnon, James G., and Milbourne, Ross D. "Are Price Equations Really Money Demand Equations on Their Heads?" *Journal of Applied Econometrics* 3 (1988): 295–305.

McCallum, Bennett T. "Price Level Determinacy with an Interest Rate Policy Rule and Rational Expectation." *Journal of Monetary Economics* 8 (November 1981): 319–29.

Sargent, Thomas J., and Wallace, Neil. "Rational Expectations, the Optimal Monetary Instrument, and the Optimal Money Supply Rule." *Journal of Political Economy* 83 (April 1975): 241–54.

Stokey, Nancy L., and Lucas, Robert E., Jr. *Recursive Methods in Economic Dynamics*. Cambridge: Harvard University Press, 1989.