Targeting inflation with a prominent role for money

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Abstract

This paper demonstrates how a target for money growth can be beneficial for an inflation targeting central bank acting under discretion. Because the growth rate of money is closely related to the change in the interest rate and the growth of real output, delegating a money growth target to the central bank makes discretionary policy more inertial, leading to better social outcomes. This delegation scheme is also compared with other schemes suggested in the literature. Although other delegation schemes are sometimes more efficient, the results indicate that giving a prominent role to a money growth indicator can be a sensible strategy for monetary policy.

Keywords: Discretion, commitment, monetary policy inertia, inflation targeting, monetary targeting.

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1 Introduction

In the modern approach to monetary policy analysis, there is often no explicit role for monetary aggregates. This is the case in theoretical analyses as well as in empirical modeling.[1] In these models, the central bank typically uses a short-term interest rate as its policy instrument, and monetary policy is assumed to affect important variables as inflation and output directly without any intermediate role for the money stock. The amount of money which must be supplied in order to support the given level of the interest rate can be determined by a money demand function, but this is not necessary to characterize the economy. Thus, money is essentially superfluous to the model.[2]

At the same time, central banks do watch monetary aggregates when pursuing monetary policy, although to a varying extent (see the contributions in European Central Bank, 2001). An interesting case in this regard is the European Central Bank (ECB), which gives money "a prominent role" in its implementation of monetary policy. This role takes the form of a reference value for the growth rate of M3 (at 4.5 percent) as one of the ECB's two "pillars" in the pursuit of its ultimate goal, price stability.[3]

Central banks offer several reasons for monitoring the developments of monetary aggregates (see European Central Bank, 2001). First, money may be an indicator of future inflation. Second, money can have an informational role if it is related to other variables that determine inflation but are imperfectly observed. And third, money is closely related to credit, and should thus be an important part of the credit channel of monetary transmission.

This paper explores yet another avenue by which money may be helpful in an inflation targeting regime when the central bank acts under discretion. As shown by Woodford (1999b), discretionary policymaking in a world with forward-looking agents is characterized by a "stabilization bias" in the sense that the optimal discre-

[1] For theoretical models, examples are Svensson (1997a), Svensson and Woodford (1999), Rotemberg and Woodford (1997), Clarida et al. (1999), and most of the models in Taylor (1999). As for empirical models, the FRB/US model of the Federal Reserve largely ignores money, see Brayton et al. (1997)

[2] McCallum (2001) argues that these models nevertheless are not "non-monetary," since the ability of the central bank to control the interest rate rests on its ability to control the monetary base. McCallum also shows that although these models may be misspecified, this is quantitatively unimportant (similar results are obtained by Ireland, 2000, and Dotsey and Hornstein, 2000).

[3] The second pillar is a "broadly-based assessment of the outlook for price developments and the risks to price stability". See, for example, European Central Bank (1998) or Angeloni et al. (2000).

tionary policy rule is less inertial than the welfare-optimizing rule obtained under precommitment.[4] Therefore, if commitments are not possible, assigning the central bank with a mechanism that makes discretionary policy more inertial may lead to better social outcomes. One such mechanism is an interest rate smoothing objective. However, if money is demand-determined, the growth rate of money is related to the change in the nominal interest rate and the growth rate of output. Therefore, a suitably designed target for money growth may also introduce inertia into the discretionary policy rule, leading to improved outcomes.[5]

The main purpose of this paper is to examine the gains from delegating a money growth target to an inflation targeting central bank. A second purpose is to compare the outcome with those from a number of other delegation schemes investigated in the literature: a conservative central bank (Svensson, 1997b; Clarida et al., 1999),[6] an interest rate smoothing objective (Woodford, 1999b), a target for the change in the output gap (Walsh, 2001), a target for nominal income growth (Jensen, 1999), and a target for average inflation over several periods (Nessén and Vestin, 2000).

In brief, the analysis shows that assigning an appropriately designed money growth target to the central bank does improve on the outcome of discretionary monetary policy, although in many of the parameter configurations analyzed, targets for the change in the output gap or for the growth of nominal income are more efficient ways of introducing inertia. Thus, even if money growth is not useful as an indicator of future inflation, a prominent role for money can be helpful for an inflation targeting central bank.[7]

The paper is organized as follows. The next Section describes the model and the delegation of monetary policy to an instrument independent (but not goal independent) central bank. Section 3 presents the results of the analysis, and Section 4 contains some final remarks. Appendix A contains some technical details.

[4]See also Svensson (1997b) for a discussion of the stabilization bias in a slightly different model.

[5]This mechanism is thus entirely due to money being related to other variables in the economy, and not due to any indicator role for money.

[6]Appointing a conservative central banker was first suggested by Rogoff (1985) as a mechanism for reducing the average inflation bias that arises when the central bank has an overly ambitious output target, not the stabilization bias analyzed here. See more below.

[7]Many authors argue that since money growth is not a reliable indicator of future inflation, central banks should not take movements in money growth into account when formulating monetary policy, see, for example, Estrella and Mishkin (1997), Bernanke et al. (1999), Svensson (1999), Gerlach and Svensson (2000), Rudebusch and Svensson (2000). However, these authors do not consider the possibility that a monetary target could help stabilizing expectations in a model with forward-looking expectations.

2 A simple model of monetary policy

2.1 The economy

The model economy is of the New-Keynesian type which is extensively used in the literature on monetary policy. Simple versions of this model are derived from microfoundations by, for example, Woodford (1996) and Rotemberg and Woodford (1997), and the model is thoroughly studied by Clarida et al. (1999). The version used here includes more inertia than the simple versions, so as to be more closely aligned with the empirical facts (see, for example, Estrella and Fuhrer, 1998). Thus, the model is essentially the same as that used by Jensen (1999) and Walsh (2001) in their closely related work.[8]

Denote by y_t the log deviation of output from its "natural" level, that is, the output gap, and by π_t the rate of inflation between periods $t-1$ and t (the log change in the price level). The output gap is determined by the aggregate demand relationship

$$y_t = \psi_y \mathrm{E}_t y_{t+1} + (1-\psi_y) y_{t-1} - \varphi\,(i_t - \mathrm{E}_t \pi_{t+1}) + \varepsilon_t^y, \tag{1}$$

where i_t is the one-period nominal interest rate set by the central bank. The parameter $\varphi > 0$ is the inverse of the intertemporal elasticity of substitution in consumption, and $0 \leq \psi_y \leq 1$ determines the degree to which agents are forward-looking in their consumption decisions. When $\psi_y = 1$, equation (1) is a log-linear approximation of the first-order Euler condition from a representative agent's consumption choice. The inclusion of the lagged output gap (with $\psi_y < 1$) can be due to habit formation, as in Fuhrer (2000). The aggregate demand disturbance ε_t^y can be interpreted as variations in the Wicksellian natural rate of interest, that is, the real interest rate that would keep output continuously at potential,[9] and is assumed to be a white noise shock with variance σ_y^2.

Inflation is determined by the expectational Phillips curve

$$\pi_t = \psi_\pi \beta \mathrm{E}_t \pi_{t+1} + (1-\psi_\pi)\pi_{t-1} + \kappa y_t + \varepsilon_t^\pi, \tag{2}$$

[8] Jensen's model differs in that it adds the terms $(1-\psi_y)$ and $(1-\psi_\pi)$ in front of $\varphi\,(i_t - \mathrm{E}_t\pi_{t+1})$ and κy_t, respectively. Also, both models allow for autocorrelated output shocks and a time-varying potential level of output, which here is implicitly kept constant.

[9] The output equation is sometimes (see, for example, Woodford, 1999b) written as

$$y_t = \mathrm{E}_t y_{t+1} - \varphi\,(i_t - \mathrm{E}_t \pi_{t+1} - r_t^n),$$

where r_t^n is the natural rate of interest. Thus, in equation (1), $\varepsilon_t^y = \varphi r_t^n$.

where $0 < \beta < 1$ is the discount factor of the representative agent, $0 \leq \psi_\pi \leq 1$ determines the degree to which imperfectly competitive firms are forward-looking when setting their prices, and $\kappa > 0$ is related to the degree of price stickiness (more stickiness implies a lower value of κ). When $\psi_\pi = 1$ this is a standard "New-Keynesian" Phillips curve, which can be derived from several different models of staggered price-setting (Roberts, 1995). Again, the inclusion of inertia ($\psi_\pi < 1$) is empirically motivated, and can be interpreted as workers being concerned about relative real wages when setting their multi-period wage contracts (Buiter and Jewitt, 1981; Fuhrer and Moore, 1995), or as some proportion of firms using a univariate rule for forecasting inflation (Roberts, 1997). The disturbance term ε_t^π is a supply shock that pushes the natural level of output (the level consistent with price stability) away from the economically efficient level, and is assumed to be white noise with variance σ_π^2.

So far, the model does not include any monetary aggregate. When the nominal interest rate is the policy instrument and the central bank aims to stabilize inflation and output, the aggregate demand and Phillips curve relationships are a complete characterization of the economy, and the model is closed by postulating either a loss function or a policy rule for the central bank. There is no need for a money market equilibrium condition, since the stock of money plays no independent role in the monetary transmission mechanism.

To analyze the role of money in this model we therefore need to specify a money demand relationship, which postulates how much money the central bank must supply in order to support a given level of the interest rate. For simplicity we use a standard specification, derived from microfoundations by Woodford (1996) and McCallum and Nelson (1999b), where the demand for real money holdings is positively related to the output gap and negatively related to the current nominal interest rate (the opportunity cost of holding money).[10] Taking first differences we obtain an expression for the growth rate of the nominal money stock as

$$\Delta m_t = \pi_t + \alpha \Delta y_t - \gamma \Delta i_t + \varepsilon_t^m, \tag{3}$$

where Δm_t is the log change in the nominal money stock and the parameters $\alpha, \gamma > 0$ both depend on the elasticity of substitution of money demand with respect to the cost of holding money balances. The money demand disturbance ε_t^m represents

[10] Empirical money demand functions (for example, Rudebusch and Svensson, 2000) are typically of the error correction type. The analysis that follows will demonstrate that even the simple specification used here introduces inertia into the discretionary policy rule. Using an error correction specification of money demand would likely lead to even more inertia in monetary policy.

velocity shocks, and is assumed to be white noise with variance σ_m^2.

2.2 Monetary policy delegation

Society is assumed to have preferences over inflation and the output gap according to the intertemporal loss function

$$\mathcal{L}_t = \mathrm{E}_t \sum_{\tau=0}^{\infty} \beta^\tau L_{t+\tau}, \tag{4}$$

where β is (again) the representative agent's discount factor and L_t is society's period loss function. This function is assumed to be quadratic in deviations of inflation and output from their respective target levels according to

$$L_t = \pi_t^2 + \lambda_y y_t^2, \tag{5}$$

where the inflation target is normalized to zero (so the model is formulated in deviations from target) and the target for output is equal to the natural level, so the target for the output gap is also zero.[11] The parameter $\lambda_y \geq 0$ measures society's preference for output stabilization relative to inflation stabilization. A quadratic loss function like (5) is standard in the monetary policy literature, and as shown by Woodford (2001), under certain conditions it represents a second-order Taylor approximation of the utility of a representative agent.[12] As the discount factor β approaches unity from below, the loss function (4)–(5) approaches a value that is proportional to the unconditional expected value of the period loss function, that is,

$$\mathrm{E}L_t = \mathrm{Var}(\pi_t) + \lambda_y \mathrm{Var}(y_t). \tag{6}$$

(See Rudebusch and Svensson, 1999, for details.) Thus, we can use (6) to evaluate the social loss function (4)–(5).

The ultimate objective of monetary policy is to choose a path for the short interest rate to minimize the loss function (4)–(5). However, the actual conduct of monetary policy is delegated to a central bank, which is assigned the task of minimizing the intertemporal loss function (4) but with the period loss function

$$\hat{L}_t = \pi_t^2 + \hat{\lambda}_y y_t^2 + \hat{\lambda}_w w_t^2, \tag{7}$$

[11] In contrast to the traditional time-consistency literature originating from Kydland and Prescott (1977) and Barro and Gordon (1983), society aims at stabilizing output around its natural level, so there is no average inflation bias of discretionary policy. Nevertheless, as seen below, there is a stabilization bias of discretionary policy which plays an important role in the model.

[12] This approximation is valid in a simple model similar to that used here, albeit without any backward-looking features.

where w_t is an additional target variable with weight $\hat{\lambda}_w$. Thus, the loss function assigned to the central bank may differ from that of society, both in terms of the variables included and in terms of the relative weights on the different target variables.[13]

The reason for giving the central bank a different loss function than that of society is that precommitments are assumed not to be feasible. If the central bank could credibly commit to an optimal monetary policy rule, it would reach the optimal outcome by minimizing the social loss function. However, when precommitments are not feasible, this is often not optimal. As famously noted by Kydland and Prescott (1977), when agents' decisions depend on their expectations of the future state of the economy (as in our model), the optimal policy rule obtained when minimizing the social loss function (under precommitment) is not "time consistent," and the discretionary policy rule where the central bank chooses the best action given the current state of the world does not minimize the social loss function.

Therefore, if the central bank cannot precommit to an optimal policy rule, but must resort to discretionary policy, it may well be beneficial to assign a different loss function to the central bank, since this may lead to better outcomes in terms of the social loss function. The most well-known example of such monetary policy delegation is given by Rogoff's (1985) conservative central bank, which reduces the inflation bias of optimal policy when society has an overly ambitious output target, as in the models of Kydland and Prescott (1977) and Barro and Gordon (1983). In this paper, society does not try to reach an output level above the natural level. Nevertheless, as is implicit in the analysis of Kydland and Prescott (1980) and more recently emphasized by Woodford (1999b), discretionary policy is inefficient also in the absence of an average inflation bias, since it is less inertial than the optimal policy under precommitment, that is, it suffers from a "stabilization bias."[14]

The intuition behind the inertia of optimal policy is fairly straightforward.[15] Suppose the economy is hit by an inflationary shock, for instance, a positive value

[13]Although the central bank is assigned its loss function from above (and so is not goal independent), it is free to choose the path of its instrument as it likes to minimize the loss function (so it is instrument dependent).

[14]Svensson (1997b) describes a similar stabilization bias in a model of the type used by Kydland and Prescott (1977) and Barro and Gordon (1983), but with endogenous persistence in unemployment. In the present model, however, there is a stabilization bias also without endogenous persistence (that is, with $\psi_y = \psi_\pi = 1$), as in Woodford (1999b). Note also that this second inefficiency of discretionary policy implies that the "just do it" approach advocated by McCallum (1997) and Blinder (1998)—setting the central bank's output target equal to the natural level—is not sufficient to reach the welfare-optimizing outcome.

[15]See Woodford (1999a,b, 2000) for details.

of ε_t^π in equation (2). If agents expect a persistent policy tightening in response to the shock, inflation expectations decrease, partly offsetting the effects of the shock on current inflation (since $\mathrm{E}_t\pi_{t+1}$ in equation (2) falls). Thus, a central bank which can commit to following such a policy rule faces a more favorable policy trade-off than under discretionary optimization, where past promises to keep policy tight are not optimal and therefore not fulfilled (so the inertial policy rule is not "time-consistent"). As a consequence, there may be gains from delegating a different loss function to the central bank if this makes the discretionary (and time-consistent) policy rule more inertial.[16]

The main issue to be investigated in this paper then is whether giving the central bank a target for money growth (that is, setting $w_t = \Delta m_t$ in equation (7)) can improve on the outcome by adding inertia to the policy rule. This particular delegation scheme will also be compared with other schemes suggested in the literature.

2.3 Optimal policy

To calculate the central bank's optimal policy rule and the resulting dynamics of the economy using numerical methods, we rewrite the model on the standard compact form

$$\begin{bmatrix} x_{1t+1} \\ \mathrm{E}_t x_{2t+1} \end{bmatrix} = A \begin{bmatrix} x_{1t} \\ x_{2t} \end{bmatrix} + Bi_t + \begin{bmatrix} \varepsilon_{t+1} \\ 0 \end{bmatrix}, \quad (8)$$

where x_{1t} is a vector of predetermined state variables; x_{2t} is a vector of forward-looking (jump) variables; ε_{t+1} is a vector of disturbances to the predetermined variables; and A, B are a matrix and a vector containing the coefficients of the model. The optimal policy rules obtained under precommitment and discretion can then be calculated using the methods developed by Backus and Driffill (1986), Currie and Levine (1993) and others, and described by Söderlind (1999).[17]

[16]Technically, the central bank's policy rule under commitment depends not only on the current state of the economy, but also on the Lagrange multipliers on the forward-looking (jump) variables (see below). These "promise-keeping" multipliers (Hansen and Sargent, 2001) capture the effects of the policymaker's promises about future policy on agents' past decisions, and thus depend on lagged values of the state variables. The discretionary policy can therefore be improved by making the central bank care also about the past, thus introducing lagged state variables in the policy rule.

[17]The main Gauss procedures used were also provided by Paul Söderlind.

With the optimal policy rule under precommitment, the dynamics of the system resulting from the optimal rule are given by

$$\begin{bmatrix} x_{1t+1} \\ \theta_{2t+1} \end{bmatrix} = M_c \begin{bmatrix} x_{1t} \\ \theta_{2t} \end{bmatrix} + \begin{bmatrix} \varepsilon_{t+1} \\ 0 \end{bmatrix}, \tag{9}$$

$$\begin{bmatrix} x_{2t} \\ i_t \\ \theta_{1t} \end{bmatrix} = C_c \begin{bmatrix} x_{1t} \\ \theta_{2t} \end{bmatrix}, \tag{10}$$

where θ_{jt} is a vector of Lagrange multipliers on x_{jt}, $j = 1, 2$. Thus, picking out the row in the matrix C_c corresponding to the policy instrument i_t, the optimal policy rule under precommitment can be expressed as a linear function of the predetermined variables and the Lagrange multipliers associated with the forward-looking variables (see also footnote 16):

$$i_t = F_c \begin{bmatrix} x_{1t} \\ \theta_{2t} \end{bmatrix}. \tag{11}$$

In contrast, under discretionary optimization, the optimal policy rule depends only on the predetermined variables according to

$$i_t = F_d x_{1t}, \tag{12}$$

and the system develops according to

$$x_{1t+1} = M_d x_{1t} + \varepsilon_{t+1}, \tag{13}$$

$$x_{2t} = C_d x_{1t}. \tag{14}$$

Appendix A shows in detail how to set up and solve the system and how to calculate the unconditional variances of the state variables, needed to evaluate the loss function (6).

2.4 Model parameterization

Empirical estimates of the model parameters vary considerably depending on estimation technique, sample period, country, and sample interval. Here, we choose a benchmark set of parameter values, intended for a quarterly specification of the model. These values are shown in Table 1. (Section 3.3 examines some alternative parameter configurations.)

Table 1: Benchmark parameter values

Output gap		Inflation		Money demand		Loss function	
ψ_y	0.50	ψ_π	0.50	α	0.75	λ_y	0.50
φ	0.20	β	0.99	γ	0.15		
σ_y	1.15	κ	0.05	σ_m	2.25		
		σ_π	2.25				

The parameters for the aggregate demand and money demand equations are taken from McCallum and Nelson's (1999c) estimates on quarterly U.S. data from 1955 to 1996. Thus, $\varphi = 0.2$, $\alpha = 0.75$, $\gamma = 0.15$, $\sigma_y = 1.15$, $\sigma_m = 2.25$. In the Phillips curve, the discount factor is set to $\beta = 0.99$, as in a large part of the literature, and the short-run slope of the Phillips curve is set to $\kappa = 0.05$, similar to the results of Lansing (2001) and Roberts (2001). The standard deviation of the inflation disturbance is set to $\sigma_\pi = 2.25$, since it is often estimated as larger than the standard deviation of the output disturbance.[18] The degree of forward-looking behavior is set to $\psi_y = \psi_\pi = 0.50$ (in the case of the Phillips curve, this is broadly consistent with the estimates of Roberts, 2001). Finally, in the benchmark specification we use a value of $\lambda_y = 0.5$, so the social loss function penalizes squared inflation deviations from target twice as heavily as squared output deviations.

3 Stabilization outcomes in different policy regimes

3.1 The benefits of targeting money growth

We first want to investigate whether assigning to the central bank a loss function that penalizes deviations of the money growth rate from a target rate (normalized to zero) results in higher social welfare. In terms of the model, we want to know whether a central bank minimizing (under discretion) the intertemporal loss function (4) but with the period loss function

$$\hat{L}_t^{MT} = \pi_t^2 + \hat{\lambda}_y y_t^2 + \hat{\lambda}_{\Delta m} (\Delta m_t)^2 \tag{15}$$

will reach a better outcome in terms of the social loss function (6) than if using society's period loss function (5). The weights $\hat{\lambda}_y, \hat{\lambda}_{\Delta m}$ will be chosen optimally, to reach the best possible outcome.

[18] See, for instance, Peersman and Smets (1999) or Rudebusch and Svensson (2000). The scale of the standard deviations only affects the scale of the loss function: only their relative size matters for the results.

Table 2: Outcomes of different policy regimes in benchmark model

Regime	Relative loss	Var(π)	Var(y)	$\hat{\lambda}_y^*$	$\hat{\lambda}_{\Delta m}^*$
Precommitment	100.00	19.26	17.37	–	–
Pure discretion	135.55	34.19	7.37	–	–
Optimized discretion	118.15	23.38	19.27	0.20	–
Money growth target	107.05	19.46	20.89	0.80	1.55

Note: The relative loss is the value of the social loss function (6) as percent of the loss under precommitment. The parameters $\hat{\lambda}_y^*, \hat{\lambda}_{\Delta m}^*$ are the optimized weights in the central bank's loss function. In the social loss function, $\lambda_y = 0.5$.

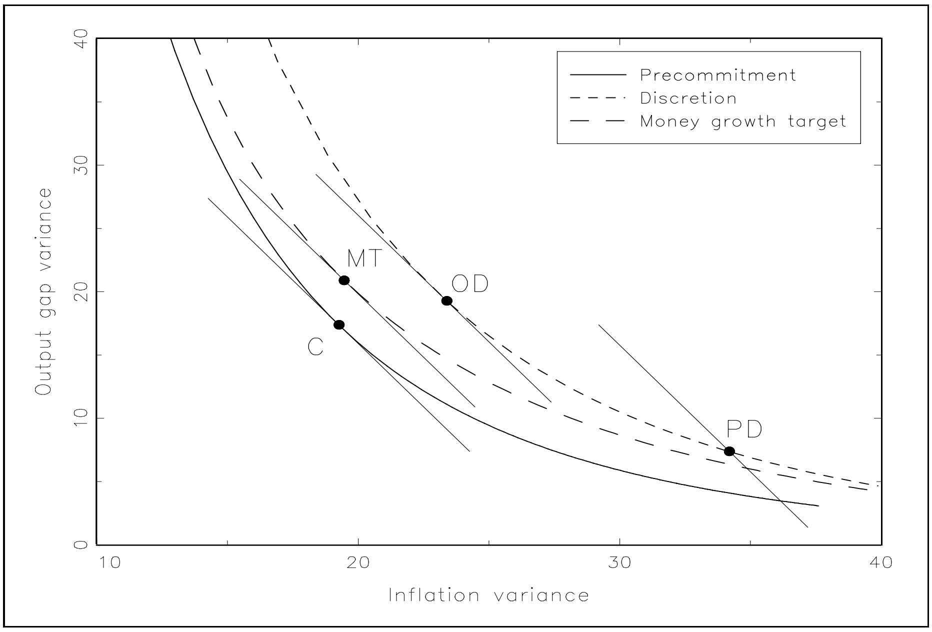
Table 2 shows the outcomes in the benchmark model of (*i*) the optimal policy under precommitment; (*ii*) the case of "pure" discretion, where the central bank is given the same loss function as society; (*iii*) the case of "optimized" discretion, where the central bank is given society's loss function, but with the preference parameter $\hat{\lambda}_y$ chosen to minimize social loss; and (*iv*) the case of money growth targeting, where the central bank is given the period loss function (15) and the preference parameters are chosen optimally. The table shows the value of the social loss function (6) (expressed as percent of the loss under precommitment), the variances of inflation and output, and (where applicable) the optimized preference parameters.

We first note that the stabilization bias of discretionary policy is fairly large: a central bank acting under pure discretion obtains a loss 35 percent higher than under the welfare-optimizing policy (precommitment).[19] The reported variances reveal that discretionary policy "over-stabilizes" the output gap, at the cost of a highly volatile inflation rate. This suggests a possible avenue for improvement: to appoint a conservative central banker, with a lower weight on output stabilization than that of society as a whole (see Clarida et al., 1999, or Svensson, 1997b). The third row shows that such a delegation scheme does improve on the outcome: with a weight of $\hat{\lambda}_y = 0.2$ instead of $\lambda_y = 0.5$, the central bank stabilizes inflation more closely (at the cost of higher output volatility), reducing the stabilization bias approximately by half. However, giving the central bank a money growth target (in the last row) improves things even more: an optimally chosen weight on the money growth target leads to even lower inflation volatility, and a considerably lower loss. A money growth target closes about 4/5 of the gap between discretionary policy and the optimal policy under precommitment, a significant reduction of the stabilization bias.[20]

[19] This is broadly consistent with the results of McCallum and Nelson (2000).

[20] It is not surprising that an optimally designed money growth target improves on the outcomes of pure and optimized discretion, since these regimes are special cases of the money targeting

Figure 1: Variance trade-offs and indifference curves in benchmark model



As an illustration of the results, Figure 1 shows the trade-offs between inflation and output variability implied by the targeting regimes. These curves are constructed by varying the weight on output stability in the central bank's loss function and calculating the unconditional variances of inflation and the output gap that result from the optimal policy rule in the different regimes. The solid line represents the trade-off available under commitment, the short-dashed line is the trade-off under discretionary optimization of the social loss function, and the long-dashed line shows the trade-off available with a money growth target (where the weight on the money growth target is set to $\hat{\lambda}_{\Delta m} = 1.55$ as in the optimal regime in Table 2). The straight lines are a family of iso-loss curves, that is, each line represents combinations of inflation and output variance that give the same value of the social welfare function (6), with $\lambda_y = 0.5$.[21]

The results from Table 2 are apparent also in Figure 1. First, the policy trade-off under precommitment is considerably more favorable than under discretion. The point "C" characterizes the optimal outcome under commitment, where an iso-loss curve is tangent to the available trade-off curve.

Second, discretionary optimization of the social loss function (with $\hat{\lambda}_y = 0.5$) does not correspond to an optimal policy under discretion: the outcome is represented by the point "PD", where the trade-off curve is not tangent to an iso-loss

regime, setting $\hat{\lambda}_{\Delta m} = 0$. Nevertheless, the large improvement in welfare is encouraging.

[21]Thus, in Var(y)–Var(π) space the iso-loss curves have slope $-1/\lambda_y = -2$.

curve. Instead, as noted by Svensson (1997b) and Clarida et al. (1999), appointing a conservative central bank (moving along the discretionary trade-off curve in the northwest direction) improves on the outcome, and the optimal outcome is given by the point "OD" (where $\hat{\lambda}_y = 0.2$).

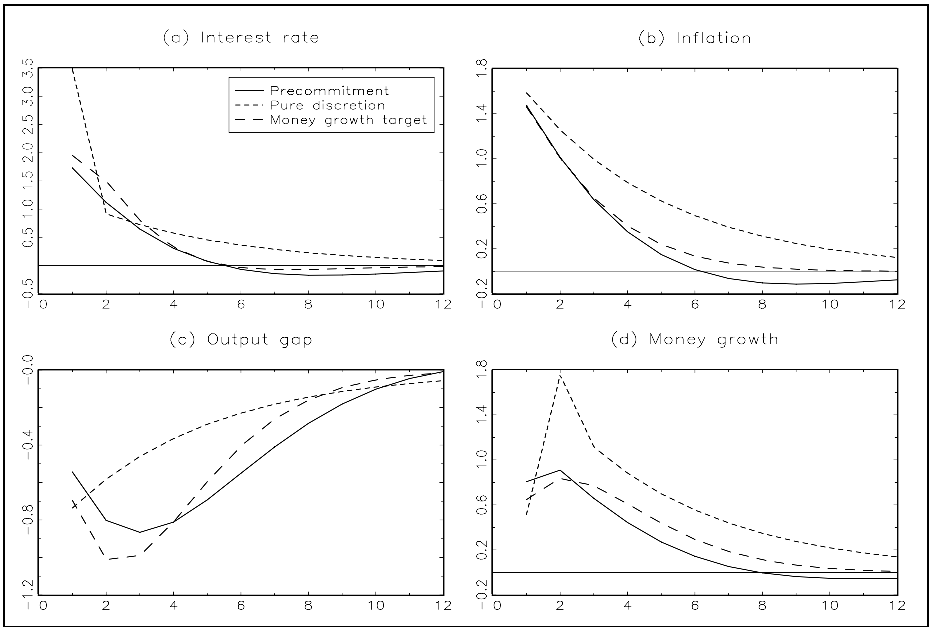
Third, assigning a money growth target to the central bank improves the trade-off facing the policymaker, since it leads to a trade-off curve that is inside that under discretion without a money growth target.[22] Thus, for any value of the social welfare parameter λ_y, there exists a policy with a money growth target that yields a better outcome in terms of the social welfare function than does a policy without a money growth target (although possibly with a different value for the central bank's preference parameter $\hat{\lambda}_y$).

The intuition behind these results is directly related to Woodford's (1999b) discussion about optimal monetary policy inertia. In general, the welfare-optimizing policy (under precommitment) is more persistent than the policy under discretion. Therefore, any changes to the central bank's loss function that makes its policy more inertial has the chance of improving the outcome of discretionary policy. In this case, the money growth target gives the central bank a reason to act more persistently in response to shocks: because money growth depends on the change in output and the interest rate, discretionary policy will respond not only to the current state of the economy but also to lagged values of the output gap and the interest rate. Since inflation is partially forward-looking, a credible persistent response to shocks has a beneficial effect on current inflation via inflation expectations.

This mechanism is illustrated in Figure 2, which shows the response of the economy to a temporary "cost shock" (of unit size), that is, a one-period increase in the inflation disturbance ε_t^{π} in equation (2). As seen in panel (a), the policy response under precommitment is less aggressive than under pure discretion. However, policy under precommitment has the effect that inflation in panel (b) not only returns gradually toward the target, but actually undershoots the target for a number of periods. Since inflation is forward-looking, this expected under-shooting has a stabilizing effect also on current inflation, which is less affected by the cost shock. With a money growth target, the responses are fairly similar to those achieved under precommitment. As a consequence, the central bank with a money growth target reaches an outcome closer to that under precommitment than does the central bank

[22]Note that because the trade-off curve under a money growth target is constructed with a fixed $\hat{\lambda}_{\Delta m}$, it does not represent the best possible outcome under a money growth target. Such a curve could be constructed by calculating the optimal $\hat{\lambda}_{\Delta m}$ for each $\hat{\lambda}_y$ along the curve. Nevertheless, the curve with a fixed weight on the money growth target still dominates that under discretion.

Figure 2: Impulse responses to a one-period cost shock (ε^{π})



acting under pure discretion.

These results indicate that there is scope in this model for a money growth target to improve on discretionary policy. This is the case even though the money stock is not directly related to inflation or output, and so is not used as an indicator of future inflation or output, nor as an information variable for the central bank. Instead, a money growth target is beneficial because it introduces inertia into the discretionary policy rule.

3.2 Alternative delegation schemes

The realization that adding inertia to the discretionary policy rule may lead to improved social outcomes has led researchers to suggest a number of delegation schemes to deliver monetary policy inertia. First, Woodford (1999b) shows that an interest rate smoothing objective improves on the discretionary policy, and almost completely eliminates the inefficiencies of discretionary policy.[23] In our model, an interest rate smoothing objective can be added by assigning the period loss function

$$\hat{L}_t^{IS} = \pi_t^2 + \hat{\lambda}_y y_t^2 + \hat{\lambda}_{\Delta i} \left(\Delta i_t\right)^2 \tag{16}$$

[23] Woodford uses a purely forward-looking version of the model (that is, with $\psi_y = \psi_\pi = 1$) and also includes a penalty on the level of the interest rate in the loss functions.

to the central bank, and choosing the parameters $\hat{\lambda}_y$ and $\hat{\lambda}_{\Delta i}$ optimally.[24]

Second, Jensen (1999) introduces inertia by letting the central bank target the growth rate of nominal income.[25] A simple formulation of nominal income growth targeting is the loss function

$$\hat{L}_t^{NIT} = \pi_t^2 + \lambda_y y_t^2 + \hat{\lambda}_{NI} (\pi_t + \Delta y_t)^2 . \tag{17}$$

As in Jensen (1999) the central bank retains the inflation and output gap targets, with the same weights as in the social loss function, while the weight on nominal income growth is chosen optimally.

Third, Walsh (2001) shows that a central bank targeting the change in the output gap, rather than the level, introduces policy inertia, and argues that this is a better description of the policy actually followed by the Federal Reserve. Thus, the central bank is given the period loss function

$$\hat{L}_t^{\Delta YT} = \pi_t^2 + \hat{\lambda}_{\Delta y} (\Delta y_t)^2 , \tag{18}$$

where, again, $\hat{\lambda}_{\Delta y}$ is optimized.

Finally, Nessén and Vestin (2000) demonstrate that letting the central bank target the average inflation rate over several periods improves on the outcome of discretionary policy. Here, a simple version of that delegation scheme is analyzed using a target for average inflation over two periods. Thus, the loss function is

$$\hat{L}_t^{AIT} = \bar{\pi}_t^2 + \hat{\lambda}_y y_t^2, \tag{19}$$

where $\bar{\pi}_t = 1/2 (\pi_t + \pi_{t-1})$, and where $\hat{\lambda}_y$ is optimized.

Many of these delegation schemes are similar, as is easily seen by substituting the money demand equation (3) into the loss function under money growth targeting, which yields

$$\hat{L}_t^{MT} = \pi_t^2 + \hat{\lambda}_y y_t^2 + \hat{\lambda}_{\Delta m} (\pi_t + \alpha \Delta y_t - \gamma \Delta i_t + \varepsilon_t^m)^2 . \tag{20}$$

Since the growth rate of money depends on the inflation rate, the change in the output gap and the change in the interest rate, the delegation schemes involving

[24]Note that the $\hat{\lambda}_y$'s have different interpretation in the different loss functions, depending on which other variables are included. (Recall that $\hat{\lambda}_y$ is the *relative* weight on the output gap.)

[25]A similar scheme, albeit using a direct "instrument rule" (when the interest rate responds to deviations of nominal income growth to target) rather than the "targeting rules" used here, has been suggested by McCallum and Nelson (1999a), and is analyzed further by Rudebusch (2000). For simplicity the formulation in (17) assumes that potential output is constant, so the growth in real output equals the growth in the output gap. Jensen and Walsh both allow for time-varying potential output.

Table 3: Outcomes of alternative delegation schemes in benchmark model

Scheme	Relative loss	Var(π)	Var(y)	$\hat{\lambda}_y^*$	$\hat{\lambda}_w^*$
Precommitment	100.00	19.26	17.37	–	–
Pure discretion	135.55	34.19	7.37	–	–
Optimized discretion	118.15	23.38	19.27	0.20	–
Money growth target	107.05	19.46	20.89	0.80	1.55
Interest rate smoothing	106.36	19.74	19.95	0.15	0.15
Output gap change target	100.23	19.42	17.18	–	1.45
Nominal income target	104.08	17.97	22.23	–	1.05
Average inflation target	115.80	20.80	23.11	0.15	–

Note: The relative loss is the value of the social loss function (6) as percent of the loss under precommitment. The parameter $\hat{\lambda}_w^*$ is the optimized weight on the additional target. The first four rows are the same as in Table 2.

money growth targeting, interest rate smoothing, output gap change targeting and nominal income growth targeting are all related. Thus it is not surprising that they should all yield similar results, that is, monetary policy inertia. It is also apparent that money growth targeting differs from the other schemes in that a third disturbance term (ε_t^m) now enters the loss function. The behavior of this disturbance will of course have important implications for the performance of money growth targeting relative to the other schemes.

Table 3 shows the results for each of the delegation schemes, using the benchmark model. (For comparison, the first four rows replicate the results from Table 2. The last column shows the optimized weight on the additional target variable, denoted $\hat{\lambda}_w$ as in the general loss function (7).) In this configuration, an output gap change target leads to the best outcome, and almost replicates the outcome of the optimal policy under precommitment. A nominal income growth target performs slightly worse, and tends to over-stabilize inflation, leading to a higher variance of output. An interest rate smoothing objective is slightly more efficient than the money growth target, whereas the average inflation target performs worst of the delegation schemes (except for optimized discretion).[26]

3.3 Sensitivity analysis

As a check on the sensitivity of the results to changes in parameter values, Table 4 shows the loss obtained from the alternative schemes as certain parameters are

[26]Nessén and Vestin (2000) analyze also longer averages of inflation, which lead to better outcomes than the two-period average used here.

Table 4: Loss in different parameter configurations

Scheme	Benchmark	$\psi_\pi = 0.25$	$\kappa = 0.3$	$\sigma_m = 4$	$\lambda_y = 0.25$	$\lambda_y = 2$
Pure discretion	135.55	106.15	117.04	135.55	132.42	138.16
Optimized discretion	118.15	101.16	114.10	118.15	118.32	116.64
Money growth target	107.05	100.26	104.89	111.26	104.42	112.20
Interest rate smoothing	106.36	101.16	109.19	106.36	104.10	111.80
Output gap change target	**100.23**	111.83	100.36	**100.23**	**100.30**	**100.06**
Nominal income target	104.08	**100.15**	**100.13**	104.08	100.80	110.10
Average inflation target	115.80	100.96	106.78	115.80	114.75	115.21

Note: Value of the social loss function (6) as percent of the loss under precommitment. Entries in bold are those with the lowest loss in each configuration.

changed from their benchmark value.[27] The relative performance of the different schemes varies across parameterizations, and comparing the outcomes gives some further insights about the different delegation schemes.

In most cases, output gap change targeting and nominal income targeting perform better than the other schemes, as in the benchmark configuration. However, when firms are not very forward-looking in their price-setting (so $\psi_\pi = 0.25$), output gap change targeting leads to a worse outcome than under pure discretion.[28] In this case, the future path of the output gap is less important for inflation, so when the central bank only aims at stabilizing the change in the gap, it chooses to close the output gap more slowly.[29] As a consequence, output gap change targeting is less successful when inflation is primarily backward-looking. On the other hand, nominal income targeting and money growth targeting are relatively successful in this configuration, although the gains from improving on the discretionary outcome are small.

When the Phillips curve is relatively steep ($\kappa = 0.3$), nominal income targeting and money growth targeting are also successful, but money growth targeting performs worse when the variance of the money demand disturbance is large ($\sigma_m = 4$), so money demand is more unstable. (The other schemes are of course not affected by the variance of money demand.)

Varying the social preference for output stabilization (λ_y) has no effect on the relative ranking of the schemes. However, interest rate smoothing, money growth

[27]Several other configurations have also been analyzed, but do not alter the main insights. The optimized preference parameters in the different configurations are shown in Table B.1 in Appendix B.

[28]Varying the degree of forward-looking behavior in the determination of output has barely no effect on the results.

[29]The output gap must still be closed in order to stabilize inflation.

targeting and, in particular, nominal income targeting perform worse as the weight on output in the social loss function increases. The performance of output gap change targeting, on the other hand, is hardly affected at all by changes in the social preference parameter λ_y.

The interest rate smoothing objective often performs slightly better than the money growth target, while the average inflation target seems to be the least successful of the delegation mechanisms.

In sum, these results suggest that although the performance of the different delegation mechanisms to some extent depends on the parameters of the model, targeting the change in the output gap seems to be the most efficient mechanism on average, followed closely by nominal income growth targeting.[30] At the same time, the performance of output gap change targeting is very sensitive to the degree of forward-looking behavior in the economy. Interest rate smoothing and money growth targeting seem to perform slightly worse, while targeting average inflation over two periods is the least efficient delegation mechanism in this setup.

4 Final remarks

In the simple model used in this paper, there are considerable gains to be made from delegating a different loss function to the central bank than that of society as a whole. In many of the configurations analyzed, the stabilization bias of discretionary policy increases the social loss by 30–40 percent relative to the welfare-optimizing policy under precommitment. While the different delegation mechanisms considered are not equally efficient, most of them yield substantial improvements in social outcome compared with the case of pure discretion. In particular, although other delegation schemes may be more efficient, there is scope in this model for using a money growth target to improve on discretionary monetary policy. In this sense, giving a prominent role to a money growth indicator can be a sensible strategy for monetary policy.

[30]These results can also be confirmed by optimizing preference parameters in a nested loss function, similar to equation (20), including the rate of inflation, the level and the growth rate of the output gap, and the change in the interest rate. In most configurations, the optimal weights on the level of the output gap and the change in the interest rate are zero, so the outcome coincides with optimal output gap change targeting in Table 4. When $\psi_\pi = 0.25$, however, there are positive weights on both the level and the change of the output gap (of 0.3 and 0.2, respectively), leading to a loss of 100.08. When $\kappa = 0.3$, nominal income growth targeting leads to a better outcome than also the nested model, apparently due to the cross product of inflation and the change in the output gap.

A Model appendix

A.1 State-space representation

The pre-determined state variables in the model are $\Delta m_t, \varepsilon_t^\pi, \varepsilon_t^y, \varepsilon_t^m, \pi_t, y_t$ and i_t. The equations for the two forward-looking variables π_t and y_t can be written

$$\psi_\pi \beta \mathrm{E}_t \pi_{t+1} = \pi_t - (1-\psi_\pi)\pi_{t-1} - \kappa y_t - \varepsilon_t^\pi, \tag{A1}$$

$$\psi_y \mathrm{E}_t y_{t+1} + \varphi \mathrm{E}_t \pi_{t+1} = y_t - (1-\psi_y) y_{t-1} + \varphi i_t - \varepsilon_t^y. \tag{A2}$$

Defining the vectors of state variables and the vector of disturbances as

$$x_{1t} = \begin{bmatrix} \varepsilon_t^\pi & \varepsilon_t^y & \varepsilon_t^m & \Delta m_{t-1} & \pi_{t-1} & y_{t-1} & i_{t-1} \end{bmatrix}', \tag{A3}$$

$$x_{2t} = \begin{bmatrix} \pi_t & y_t \end{bmatrix}', \tag{A4}$$

$$\varepsilon_t = \begin{bmatrix} \varepsilon_t^\pi & \varepsilon_t^y & \varepsilon_t^m & 0 & 0 & 0 & 0 \end{bmatrix}', \tag{A5}$$

the model can be written in compact form as

$$A_0 \begin{bmatrix} x_{1t+1} \\ \mathrm{E}_t x_{2t+1} \end{bmatrix} = A_1 \begin{bmatrix} x_{1t} \\ x_{2t} \end{bmatrix} + B_1 i_t + \begin{bmatrix} \varepsilon_{t+1} \\ 0 \end{bmatrix}, \tag{A6}$$

or

$$\begin{bmatrix} x_{1t+1} \\ \mathrm{E}_t x_{2t+1} \end{bmatrix} = A x_t + B i_t + \begin{bmatrix} \varepsilon_{t+1} \\ 0 \end{bmatrix}, \tag{A7}$$

where

$$x_t = \begin{bmatrix} x_{1t} \\ x_{2t} \end{bmatrix}, \quad A = A_0^{-1} A_1, \quad B = A_0^{-1} B_1. \tag{A8}$$

The parameter matrices and vectors are given by

$$A_0 = \begin{bmatrix} I_7 & 0_{7\times 2} & \\ 0_{1\times 7} & \psi_\pi \beta & 0 \\ 0_{1\times 7} & \varphi & \psi_y \end{bmatrix}, \tag{A9}$$

$$A_1 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & -\alpha & \gamma & 1 & \alpha \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 & -(1-\psi_\pi) & 0 & 0 & 1 & -\kappa \\ 0 & -1 & 0 & 0 & 0 & -(1-\psi_y) & 0 & 0 & 1 \end{bmatrix}, \tag{A10}$$

$$B_1 = \begin{bmatrix} 0 & 0 & 0 & -\gamma & 0 & 0 & 1 & 0 & \varphi \end{bmatrix}', \tag{A11}$$

and the vector ε_t of disturbances has covariance matrix Σ_ε with $\sigma_\pi^2, \sigma_y^2, \sigma_m^2$ as the first three elements on the diagonal and zeros elsewhere.

To analyze all different targeting regimes within the same framework, it is useful to define a vector of potential goal variables as

$$z_t = \begin{bmatrix} \pi_t & y_t & \Delta m_t & \Delta i_t & \Delta y_t & \pi_t + \Delta y_t & \bar{\pi}_t \end{bmatrix}'. \tag{A12}$$

These goal variables can then be written in terms of the state variables as

$$z_t = C_x x_t + C_i i_t, \tag{A13}$$

where

$$C_x = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 & -\alpha & \gamma & 1 & \alpha \\ 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & -1 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1/2 & 0 & 0 & 1/2 & 0 \end{bmatrix}, \quad C_i = \begin{bmatrix} 0 \\ 0 \\ -\gamma \\ 1 \\ 0 \\ 0 \\ 0 \end{bmatrix}. \tag{A14}$$

The central bank's period loss function can be written as

$$\hat{L}_t = z_t' K z_t, \tag{A15}$$

where K is a matrix of preference parameters with diagonal

$$\left\{ \hat{\lambda}_\pi, \ \hat{\lambda}_y, \ \hat{\lambda}_{\Delta m}, \ \hat{\lambda}_{\Delta i}, \ \hat{\lambda}_{\Delta y}, \ \hat{\lambda}_{NI}, \ \hat{\lambda}_{\bar{\pi}} \right\}, \tag{A16}$$

and zeros elsewhere. The loss function for the different targeting regimes are obtained by assigning non-zero values for the following $\hat{\lambda}$'s:

1. Pure commitment and discretion: $\hat{\lambda}_\pi = 1$, $\hat{\lambda}_y = \lambda_y$;

2. Optimized discretion: $\hat{\lambda}_\pi = 1$, $\hat{\lambda}_y$ optimized;

3. Monetary targeting: $\hat{\lambda}_\pi = 1$, $\hat{\lambda}_y$, $\hat{\lambda}_{\Delta m}$ optimized;

4. Interest rate smoothing: $\hat{\lambda}_\pi = 1$, $\hat{\lambda}_y$, $\hat{\lambda}_{\Delta i}$ optimized;

5. Output gap change targeting: $\hat{\lambda}_\pi = 1$, $\hat{\lambda}_{\Delta y}$ optimized;

6. Nominal income growth targeting: $\hat{\lambda}_\pi = 1$, $\hat{\lambda}_{NI}$ optimized;

7. Average inflation targeting: $\hat{\lambda}_{\bar{\pi}} = 1$, $\hat{\lambda}_y$ optimized;

with all other $\hat{\lambda}$'s set to zero.

In terms of the state vector x_t, the loss function is

$$\begin{aligned}
\hat{L}_t &= z_t' K z_t \\
&= \begin{bmatrix} x_t' & i_t' \end{bmatrix} \begin{bmatrix} C_x' \\ C_i' \end{bmatrix} K \begin{bmatrix} C_x & C_i \end{bmatrix} \begin{bmatrix} x_t \\ i_t \end{bmatrix} \\
&= x_t' C_x' K C_x x_t + x_t' C_x' K C_i i_t + i_t' C_i' K C_x x_t + i_t' C_i' K C_i i_t \\
&= x_t' Q x_t + x_t' U i_t + i_t' U' x_t + i_t' R i_t, \qquad \text{(A17)}
\end{aligned}$$

where

$$\begin{aligned}
Q &= C_x' K C_x, \qquad \text{(A18)} \\
U &= C_x' K C_i, \qquad \text{(A19)} \\
R &= C_i' K C_i. \qquad \text{(A20)}
\end{aligned}$$

Thus, the problem is rewritten on standard form, and we can go on to use the methods described by Söderlind (1999) to calculate the optimal policy rule under precommitment and discretion.

A.2 Unconditional variances

Under precommitment, the system develops according to (see Söderlind, 1999)

$$\begin{aligned}
k_{1t+1} &= M_c k_{1t} + \varepsilon_{k1t+1}, \qquad \text{(A21)} \\
k_{2t} &= C_c k_{1t}, \qquad \text{(A22)}
\end{aligned}$$

where

$$k_{1t} = \begin{bmatrix} x_{1t} \\ \theta_{2t} \end{bmatrix}, \quad k_{2t} = \begin{bmatrix} x_{2t} \\ i_t \\ \theta_{1t} \end{bmatrix}, \quad \varepsilon_{k1t+1} = \begin{bmatrix} \varepsilon_{t+1} \\ 0_{2\times 1} \end{bmatrix}, \tag{A23}$$

and where θ_{jt} is the vector of Lagrange multipliers associated with x_{jt}. Thus, letting $\Sigma_{\varepsilon k1}$ be the covariance matrix of ε_{k1t}, the covariance matrix of the state variables and Lagrange multipliers in k_{1t} is given by

$$\Sigma_{k1} = M_c \Sigma_{k1} M_c' + \Sigma_{\varepsilon k1}, \tag{A24}$$

or[31]

$$\begin{aligned} \text{vec}\left(\Sigma_{k1}\right) &= \text{vec}\left(M_c \Sigma_{k1} M_c'\right) + \text{vec}\left(\Sigma_{\varepsilon k1}\right) \\ &= \left(M_c \otimes M_c\right) \text{vec}\left(\Sigma_{k1}\right) + \text{vec}\left(\Sigma_{\varepsilon k1}\right) \\ &= \left(I - M_c \otimes M_c\right)^{-1} \text{vec}\left(\Sigma_{\varepsilon k1}\right), \end{aligned} \tag{A25}$$

and the covariance matrix of k_{2t} is

$$\Sigma_{k2} = C_c \Sigma_{k1} C_c'. \tag{A26}$$

Under discretion, the optimal policy rule is of the form

$$i_t = F_d x_{1t}, \tag{A27}$$

and the system develops according to

$$x_{1t+1} = M_d x_{1t} + \varepsilon_{t+1}, \tag{A28}$$

$$x_{2t} = C_d x_{1t}. \tag{A29}$$

Thus, the covariance matrix of the predetermined varibles in x_{1t} is given by

$$\Sigma_{x1} = \left(I - M_d \otimes M_d\right)^{-1} \text{vec}\left(\Sigma_\varepsilon\right), \tag{A30}$$

and the covariance matrix of x_{2t} is

$$\Sigma_{x2} = C_d \Sigma_{x1} C_d'. \tag{A31}$$

[31] Use the rules $\text{vec}(A+B) = \text{vec}(A) + \text{vec}(B)$ and $\text{vec}(ABC) = (C' \otimes A)\,\text{vec}(B)$.

B Optimized preference parameters

Table B.1: Optimized central bank preferences in different parameter configurations

Scheme	Benchmark	$\psi_\pi = 0.25$	$\kappa = 0.3$	$\sigma_m = 4$	$\lambda_y = 0.25$	$\lambda_y = 2$
Optimized discretion						
$\hat{\lambda}_y^*$	0.20	0.30	0.35	0.20	0.10	0.60
Money growth target						
$\hat{\lambda}_y^*$	0.80	0.30	0.25	0.30	0.20	2.10
$\hat{\lambda}_{\Delta m}^*$	1.55	0.05	0.10	0.25	0.55	1.30
Interest rate smoothing						
$\hat{\lambda}_y^*$	0.15	0.30	0.05	0.15	0.05	0.60
$\hat{\lambda}_{\Delta i}^*$	0.15	0.00	0.05	0.15	0.15	0.15
Output gap change target						
$\hat{\lambda}_{\Delta y}^*$	1.45	3.30	0.40	1.45	0.55	10.60
Nominal income target						
$\hat{\lambda}_{NI}^*$	1.05	0.50	0.95	1.05	1.00	1.45
Average inflation target						
$\hat{\lambda}_y^*$	0.15	0.30	0.25	0.15	0.10	0.55

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