Targeting Nominal Income Growth or Inflation?*

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Abstract

Within a simple New Keynesian model emphasizing forward-looking behavior of private agents, I evaluate optimal nominal income growth targeting versus optimal inflation targeting. When the economy under consideration is mainly subject to shocks that do not involve monetary policy trade-offs for society, inflation targeting is preferable. Otherwise, nominal income growth targeting may be superior because it induces inertial interest rate behavior that improves the inflation-output gap trade-off. Somewhat paradoxically, inflation targeting is relatively less favorable the more society cares for inflation, and the more persistent are the effects of inflation-generating shocks.

Keywords: Nominal income growth targeting; inflation targeting; monetary policy; interest rate inertia.

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1. Introduction

In recent decades, several rather dramatic changes in the frameworks for monetary policy conduct have occurred around the world. Many countries have adopted, for example, various forms of inflation targeting regimes, and 11 European countries have formed the European Monetary Union necessitating a re-thinking of monetary policy strategies for both member and non-member countries. Such events, and the likely need for providing guidelines for appropriate institutional design in, e.g., former Eastern European countries and many developing countries, have without doubt been crucial impetus in the current revival of monetary policy issues in academic research.

It is not unfair to say that within the newer literature, there is now a broad consensus about the desirability of central bank independence. I.e., that monetary policy is insulated from, say, political pressures which could lead to excess macroeconomic fluctuations (Alesina, 1988), or even permanent inefficiencies in monetary policy (e.g., the famous inflation bias of Kydland and Prescott, 1977; Barro and Gordon, 1983). Also, recent research appears to have converged on a model framework of the type dubbed the "New Neoclassical Synthesis" by Goodfriend and King (1997). This framework emphasizes forward-looking behavior (and, thus, intertemporal optimization by private agents) and incomplete nominal adjustment of prices featured in New Keynesian theory.[1,2] Adherence to these models with (some to perfect) micro foundations has, of course, the advantage that evaluation of different monetary policy scenarios is less vulnerable to the Lucas (1976) critique.

Where consensus breaks down, is in terms of the modeling of monetary regimes, and in terms of which macroeconomic aggregates should determine the course of monetary policy. On the first point, some model a monetary regime as a set of incentive mechanisms for central bankers, usually labeled "targeting regimes," which induce a behavior that achieves various policy goals (e.g., Rogoff, 1985, Rudebusch and Svensson, 1999, Svensson, 1999a, Walsh, 1998, Chap. 8). Others mainly model a regime as explicit policy instructions that the central bank is committed to follow. For example, "instrument rules" in conformity with the celebrated Taylor (1993) rule.[3] On the second point, some, e.g., suggest price

[1]See, e.g., Bernanke and Woodford (1997), Clarida et al. (1999a,b), King and Wolman (1996, 1999), McCallum and Nelson (1999a,b), Rotemberg and Woodford (1997, 1999), Svensson (1999a,b), Woodford (1998), for just a few examples of this line of research.

[2]There exists rarely rules without exceptions, and this also applies here. Another recent line of research focuses on the real effects of money within flexible price models featuring various transaction frictions. See, e.g., Christiano et al. (1998) and Cooley and Quadrini (1999).

[3]There is not agreement about terminology. Some, e.g., McCallum and Nelson (1999a), argue that a Taylor rule where the interest rate responds to inflation, warrants the labelling "inflation targeting." Svensson (1999a) argues instead that the proper label for such behavior is "responding to inflation." I am, in terms of terminology, more in line with the latter denomination.

stability as the overriding objective of monetary policy (King and Wolman, 1999), while others favor more "flexible" inflation targeting where some priority is given to stabilizing the output gap (Svensson, 1999a). In addition, some suggest that monetary policy should respond to intermediate variables like, for example, nominal income growth (McCallum and Nelson, 1999a) or lagged values of the interest rate (Rotemberg and Woodford, 1999).[4]

The purpose of this paper is to contribute to the issue of which aggregates should guide monetary policy. More specific, I compare the performance of two targeting regimes (in the sense of Svensson, 1999a) within the above-mentioned framework: inflation targeting (henceforth, IT) and nominal income growth targeting (henceforth, NIGT). The focus on IT is motivated by the fact that inflation is a primary goal variable which, together with the output gap, appear in the social welfare criterion. (Another motivation is that its enormous academic and real-life attention make it a natural reference point against which alternatives are evaluated.) The choice of nominal income growth as an alternative nominal anchor is motivated by its ability of serving a useful, and heretofore unrecognized, role in economies with forward-looking behavior as will be clarified below.[5]

It should be stressed that targeting is understood to be *flexible*, i.e., the monetary authority is designated to pay attention to the real side of the economy (the output gap), in addition to the nominal target variable whatever that may be.[6] Also, in each case, the strength of this attention is chosen at the institutional design stage so as to minimize the welfare loss of society. This focus on *optimal* regimes, of course, eliminates any arbitrariness in the comparison of regime performance. Moreover, it has the side effect of identifying how various central structural features of an economy affect the optimal weights on real versus nominal objectives in monetary policymaking (irrespective of whether the regime is that of IT or NIGT).

The main finding of the paper is that even though society's welfare depends on the variability of the output gap and inflation, it may be desirable for society to adopt NIGT rather than IT. The mechanism behind the potential superiority of NIGT is, to the best of my knowledge, a new one. As recently emphasized by Woodford (1998), *inertial* in-

[4] Furthermore, the literature contains several analyses where various lags and (expected) leads of various aggregates are determinants of monetary policy. See, e.g., the contributions in Taylor (1999).

[5] NIGT has of course also received considerable academic attention, but recently not of a magnitude remotely comparable to that of IT. The classic reference is Bean (1983). See also Hall and Mankiw (1994) or McCallum and Nelson (1999a) for recent collections of arguments in favor of nominal income (growth) targeting. Beetsma and Jensen (1999) have recently shown that targeting nominal income growth in the model of Lockwood and Philippopoulos (1994) (a dynamic version of Barro and Gordon, 1983), mitigates the model's time-varying inflation bias.

[6] The approach therefore contrasts with earlier literature that usually considers nominal income growth within an "instrument rule" framework (e.g., McCallum and Nelson, 1999a,b), or evaluates it in a "strict" targeting sense, that is, as the overriding objective for monetary policy.

terest rate behavior characterizes optimal monetary policy under commitment in models with forward-looking behavior. The main reason is that current inflation is a function of expected future inflation. If the economy is then hit by a temporary inflationary shock that requires contractive monetary policy, the trade-off between inflation and the output gap becomes more favorable if the contraction is expected to persist. This follows as expected future inflation will fall which reduces current inflation. Hence, a given reduction in inflation can be "bought" at a smaller, but persistent, reduction in the output gap (see also Rotemberg and Woodford, 1997).

The problem with this policy, however, is that it is time inconsistent. A central bank with preferences for the output gap and inflation (as is the case under IT), would not be willing to let a contraction persist under discretionary policymaking: when the inflationary shock is worn out, it is optimal not to contract anymore. In anticipation of this, expected inflation will not play the stabilizing role for current inflation as it does under commitment. A central bank operating under NIGT will, in contrast, be forced to let a contraction persist: when the inflationary shock has passed, the economy is returning to steady state, which implies higher nominal income growth. To stabilize nominal income growth, the central bank continues the contraction and thereby acts more in accordance with the commitment policy plan.

The extent to which this is sufficient to render NIGT superior, is examined numerically within a relatively simple version of the model types mentioned above. It turns out that when the economy is mainly subject to shocks that do not involve monetary policy trade-offs for society, IT is preferable. This follows as it is then advantageous that central bank preferences are aligned with those of society. But when shocks causing an inflation-output gap trade-off in monetary policy are important, NIGT is found to be superior because it induces inertial interest rate behavior; a behavior that results in more stable inflation than under IT.

Somewhat paradoxically, it turns out that IT is relatively less favorable the more society cares for inflation, and the more persistent are the effects of inflation-generating shocks. This is because the relative advantage of NIGT in terms of stabilizing inflation is valued more by society when inflation shocks are predominant and inflation is disliked by society.[7]

The rest of the paper is structured as follows. The main body of Section 2 presents the

[7] It may also be noted that for most of the cases considered, the variability of nominal interest rates is lowest under NIGT. If high variability of interest rates *per se* is considered harmful (as it may "whipsaw the market," Goodfriend, 1991), this constitutes another (informal) argument in favor of NIGT. On the other hand, if the empirically well-documented tendency for central bankers to "smooth" interest rates is considered too excessive (cf. Goodhart, 1997), introducing additional inertia into policymaking by NIGT may be undesirable.

model, and Section 2.1 describes monetary policy under the benchmark case of precommitment. Section 3 describes discretionary policymaking under IT and NIGT. In Section 4.1, the baseline parameter configuration used in the numerical simulations is presented, and Section 4.2 contains the results for this set of parameters. Various deviations from the baseline are presented and discussed in Section 4.3. In Section 5, further discussions of the results are offered along with suggestions for further research. Section 6 concludes. Some technicalities are relegated to the appendix.

2. The model

The model economy is a particularly simple version of dynamic models that have recently been extensively applied in the literature on monetary policy evaluation (see Footnote 1). Simplicity serves to highlight the incentive issues of optimal monetary policy under various targeting regimes, and implies that the economy is described by just two reduced-form equations; one for aggregate demand, and one for aggregate supply. Time is discrete, and aggregate demand in the closed economy in periods $t = 1, 2, 3..., \infty$ is determined by the following intertemporal "IS curve:"

$$\begin{aligned} y_t &= \theta y_{t-1} + (1-\theta)\,\mathrm{E}_t y_{t+1} - (1-\theta)\,\sigma\,(i_t - \mathrm{E}_t \pi_{t+1}) + g_t, \qquad (1) \\ 0 &\leq \theta < 1, \quad \sigma > 0, \quad y_0 = 0 \text{ given,} \end{aligned}$$

where y_t is output measured as the log deviation from trend, i_t is the (short) nominal interest rate assumed to be the monetary policy instrument. The inflation rate is π_t (the log difference of prices between $t-1$ and t). E_t is the expectations operator conditional upon all information up to, and including, period t. For the special case of $\theta = 0$, (1) approximates the path of demand arising from the Euler equation characterizing optimal aggregate consumption choices by conventional "Ramsey-type" individuals (see, e.g., King and Wolman, 1999; Rotemberg and Woodford, 1998; McCallum and Nelson, 1999b). Parameter σ can then be interpreted as the rate of intertemporal substitution (times the steady-state ratio of interest rate sensitive demand to total demand) determining to which extent changes in the real exchange rate, $i_t - \mathrm{E}_t \pi_{t+1}$, affect expected spending growth. The variable g_t represents other spending (for example government spending), and is taken to be stochastic and driven by an AR(1) process:

$$g_t = \gamma_g g_{t-1} + \zeta_t^g, \quad 0 \leq \gamma_g < 1, \quad t = 1, 2, ..., \infty, \quad g_0 = 0 \text{ given,} \qquad (2)$$

where ζ_t^g is a mean-zero innovation with standard deviation σ_g. For mainly empirical reasons (see, e.g., Fuhrer, 1998; Rudebusch and Svensson, 1999, on U. S. data), the specification of aggregate demand also allows for endogenous persistence in demand when $0 < \theta < 1$.[8] As will be clear below, however, this has little to no effects on the results.

Aggregate supply is modelled by an expectations-augmented "Phillips curve:"

$$\begin{aligned} \pi_t &= \phi\pi_{t-1} + (1-\phi)\,\beta \mathrm{E}_t\pi_{t+1} + (1-\phi)\,\kappa\,(y_t - y_t^n) + \varepsilon_t, \\ 0 &\leq \phi < 1, \quad \kappa > 0, \quad 0 < \beta < 1, \quad \pi_0 = 0 \text{ given,} \end{aligned} \tag{3}$$

where y_t^n is the "natural" rate of output, or, potential output; i.e., an output deviation from trend that would prevail in absence of any price rigidities. It is stochastic, thereby reflecting technology shocks, and driven by the following AR(1) process:

$$y_t^n = \gamma_y y_{t-1}^n + \zeta_t^y, \quad 0 \leq \gamma_y < 1, \quad t = 1, 2, ..., \infty, \quad y_0^n = 0 \text{ given,} \tag{4}$$

where ζ_t^y is a mean-zero innovation with standard deviation σ_y. In the special case of $\phi = 0$, the structure of (3) resembles what Roberts (1995) has labelled the New Keynesian Phillips Curve, which can be derived from a variety of supply side models. For example, it can be shown to approximate the aggregate pricing equation that emerges from monopolistically competitive firms' optimal behavior in Calvo's (1983) model of staggered price determination (see, e.g., Yun, 1996; Woodford, 1996; and Rotemberg and Woodford, 1998, for a derivation).[9] In such a setting, current aggregate prices are a function of past period's prices (remember $\pi_t \equiv p_t - p_{t-1}$ where p_{t-1} is the log price level) as some firms cannot change their prices, but they are also a function of expected future prices as firms setting prices today know that there is a risk of being refrained from adjusting to future economic events. To protect expected real profits, expectations about future aggregate prices then become important. This will be to an extent determined by β, which is the discount factor.[10] The appearance of the output and natural output terms in (3) reflects

[8] As recently stressed by Fuhrer (1998), the motivation could, of course, also be theoretical when habit formation is important in intertemporal consumption decisions.

[9] In Calvo's model, each firm faces in every period a state-independent probability of being able to change its price. As shown by Dotsey et al. (1999), if the probability is state-dependent, shifts in the average inflation rate affect the parameters of (3). Analyses of regime changes implying large differences in average inflation will therefore be vulnerable to the Lucas critique. In the regimes to be considered in this paper, however, average inflation rates are identical. Treating the parameters as structural is therefore less critical.

[10] Aggregate supply curves like (3) has been criticized for not being conformable with the "natural rate hypothesis," see, e.g., McCallum and Nelson (1999a). However, in all the simulations that follow, β is set close to one, so this deviation from the hypothesis will be of negligible magnitude.

that price setters determine prices as a mark-up over marginal costs, and that these costs are affected by how much actual output exceeds potential. Hence, the parameter κ comprises the sensitivity of prices to marginal costs and the proportionality between marginal costs and the *output gap*, $y_t - y_t^n$.[11]

Again, for mainly empirical reasons, endogenous inflation persistence is introduced by allowing for $0 < \phi < 1$. It is, e.g., on U. S. data difficult to reject that inflation behaves inertial (cf. Fuhrer, 1997; Fuhrer and Moore, 1995; Roberts, 1997, 1998; Rudebusch and Svensson, 1999). This could be due to overlapping nominal contracts aimed at, e.g., securing real wage levels comparable to existing and expected real wages (Fuhrer and Moore, 1995). Alternatively, it could be an indication of non-rational expectations in price formation (such that lagged inflation appears because of some degree of, say, adaptive expectations formation; cf. Roberts, 1997, 1998). The particular reason is not of importance here. The inclusion of endogenous persistence is, however, of quantitative importance for the results, although not necessary for their main qualitative characteristics.

Finally, I follow several authors in adding a disturbance, ε_t, to the aggregate supply curve (see, e.g., Clarida et al., 1999a; Fuhrer and Moore, 1995; Rudebusch and Svensson, 1999; Svensson, 1999a,b). Following Clarida et al. (1999a), I label it a cost-push shock. They interpret it as representing anything apart from the output gap that affects marginal costs. That could, for example, be the extent to which the conditions for the assumed proportionality between marginal costs and the output gap fails to hold, cf. Footnote 11. In addition, they note that in empirical estimates of inflation equations like (3), a non-negligible part of inflation is left unexplained by the output gap. The presence of this shock is of *all* importance for the ensuing results because it, within this particular model set-up, induces the trade-off in monetary policymaking that matters in the design of targeting regimes. As with the other exogenous disturbances, the cost-push shock is assumed to follow an AR(1) process:

$$\varepsilon_t = \gamma_\varepsilon \varepsilon_{t-1} + \zeta_t^\varepsilon, \quad 0 \leq \gamma_\varepsilon < 1, \quad t = 1, 2, ..., \infty, \quad \varepsilon_0 = 0 \text{ given}, \tag{5}$$

where ζ_t^ε is a mean-zero innovation with standard deviation σ_ε. All stochastic innovations in the model (ζ_t^g, ζ_t^y and ζ_t^ε) are white noise and uncorrelated at all leads and lags.

The policy regimes to be considered are all evaluated according to a welfare loss function

[11] Galí and Gertler (1999) provide details on the conditions under which the proportionality between the output gap and marginal costs holds.

of society. This function is assumed to be

$$L = \mathrm{E}_0 \sum_{t=1}^{\infty} \beta^{t-1} \left[\lambda \left(y_t - y_t^n \right)^2 + \pi_t^2 \right], \quad \lambda > 0, \tag{6}$$

i.e., the unconditional expectation of the discounted sum of quadratic deviations of the output from potential and quadratic deviations of inflation from a target of zero. Such a loss function can under some circumstances be derived as an approximation to the (negative of the) utility function of a representative consumer in the economy as demonstrated by, e.g., Rotemberg and Woodford (1998) for the case of $\phi = \theta = 0$. However, to the extent that endogenous persistence in the economy is present, (6) may not be an accurate approximation of welfare, cf. the discussion in Fuhrer (1998). I take a rather pragmatic stand on this, and simply adopt (6) because it is the loss function that has been applied in virtually all literature on monetary policy issues in the past decades.

A few closing remarks on (6) are in order. While the choice of an optimal rate of inflation of zero is merely a convenient normalization, the choice of an output gap target of zero requires clarification. Since the assumptions underlying (3) include monopoly power in goods markets, it follows that potential output is too low. This speaks in favor of including a positive target value for the output gap in (6). As is well known, however, under discretionary policymaking, this creates incentives for permanently raising output above the natural rate. In this rational expectations framework, an inflation bias of the Barro and Gordon (1983) kind would emerge. Such permanent credibility problems could conceivably be corrected through proper design of target values under the targeting regimes to be considered (see, e.g., Beetsma and Jensen, 1999; Jensen, 2000; Svensson, 1997a). In the present model, however, the issue is complicated by the fact that even if the policymaker could precommit, the optimal plan implies initial positive output gap and inflation, which gradually vanish in the long run. (Loosely speaking, it is optimal to start with an "inflation surprise" and then never do it again.) To mimic such a pattern, the choice of optimal target value for the output gap would have to balance the desirability of a short-run output gain against the loss of a permanent inflation bias. These considerations muddle the main messages of the paper, and it is thus simply assumed that the desired output gap is zero.

2.1. Benchmark: Optimal policy under precommitment

Consider now the case where policy can be conducted as if the monetary authority at $t = 0$ precommits to a policy plan for *all* remaining periods. As is well known, this policy is generally not time-consistent in rational expectations models, and I do not consider it as particularly realistic that authorities act in a time-inconsistent manner. The associated optimal policy will, however, serve as a useful benchmark against which policy under the ensuing targeting regimes can be evaluated.

To derive this solution, and the associated societal welfare loss, it is convenient to express the model in state-space form. Define first the output gap as $x_t \equiv y_t - y_t^n$. Then, the system formed by (1) and (3) can be re-stated as

$$x_t = \theta x_{t-1} + (1-\theta)\,\mathrm{E}_t x_{t+1} - (1-\theta)\,\sigma\,(i_t - \mathrm{E}_t\pi_{t+1}) + \mu_t, \tag{7}$$

$$\pi_t = \phi\pi_{t-1} + (1-\phi)\,\beta\mathrm{E}_t\pi_{t+1} + (1-\phi)\,\kappa x_t + \varepsilon_t, \tag{8}$$

with $\mu_t \equiv g_t - y_t^n + \theta y_{t-1}^n + (1-\theta)\mathrm{E}_t y_{t+1}^n$. Now define $\mathbf{Z}_t \equiv [\mathbf{X}_t' \quad \boldsymbol{\chi}_t']'$ as the (column) vector of predetermined ($\mathbf{X}_t$) and forward-looking ($\boldsymbol{\chi}_t$) variables, with

$$\mathbf{X}_t \equiv \begin{bmatrix} g_t & y_t^n & y_{t-1}^n & \varepsilon_t & x_{t-1} & \pi_{t-1} \end{bmatrix}', \quad \boldsymbol{\chi}_t \equiv [x_t \quad \pi_t]'.$$

The dynamics of the model can then be written as

$$\begin{bmatrix} \mathbf{X}_{t+1} \\ \mathrm{E}_t\boldsymbol{\chi}_{t+1} \end{bmatrix} = \mathbf{A}\begin{bmatrix} \mathbf{X}_t \\ \boldsymbol{\chi}_t \end{bmatrix} + \mathbf{B}i_t + \begin{bmatrix} \boldsymbol{\zeta}_{t+1} \\ \mathbf{0}_{2\times 1} \end{bmatrix}, \tag{9}$$

with

$$\mathbf{A} \equiv \begin{bmatrix} \gamma_g & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \gamma_y & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \gamma_\varepsilon & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ -\frac{1}{1-\theta} & \frac{1-(1-\theta)\gamma_y}{1-\theta} & -\frac{\theta}{1-\theta} & \frac{\sigma}{(1-\phi)\beta} & -\frac{\theta}{1-\theta} & \frac{\sigma\phi}{(1-\phi)\beta} & \frac{\beta+(1-\theta)\sigma\kappa}{(1-\theta)\beta} & -\frac{\sigma}{(1-\phi)\beta} \\ 0 & 0 & 0 & -\frac{1}{(1-\phi)\beta} & 0 & -\frac{\phi}{(1-\phi)\beta} & -\frac{\kappa}{\beta} & \frac{1}{(1-\phi)\beta} \end{bmatrix},$$

$\mathbf{B} \equiv \begin{bmatrix} \mathbf{0}_{1\times 6} & \sigma & 0 \end{bmatrix}'$, and $\boldsymbol{\zeta}_{t+1} \equiv \begin{bmatrix} \zeta_{t+1}^g & \zeta_{t+1}^y & 0 & \zeta_{t+1}^\varepsilon & \mathbf{0}_{1\times 2} \end{bmatrix}'$. Since $\lambda x_t^2 + \pi_t^2 = \mathbf{Z}_t'\mathbf{Q}\mathbf{Z}_t$, where

$$\mathbf{Q} \equiv \begin{bmatrix} \mathbf{0}_{6\times 6} & \mathbf{0}_{6\times 2} \\ \mathbf{0}_{2\times 6} & \mathbf{K} \end{bmatrix}, \quad \mathbf{K} \equiv \begin{bmatrix} \lambda & 0 \\ 0 & 1 \end{bmatrix},$$

it follows that the decision problem involves solving the linear-quadratic problem

$$J(\mathbf{X}_1) = \min_{\{i_t\}_{t=1}^{\infty}} \mathrm{E}_1 \left[\sum_{t=1}^{\infty} \beta^{t-1} \mathbf{Z}_t' \mathbf{Q} \mathbf{Z}_t \right],$$

where the minimization is subject to (9) taking as given $\mathbf{X}_1$. The numerical solution method is outlined in Appendix A, and the solution's associated societal welfare loss, dynamics of the economy, evolution of the interest rate, and unconditional covariance matrix of $\mathbf{Z}_t$, are, respectively, provided by (A.6), (A.7), (A.8) and (A.9). In the following, the main features of the precommitment solution are described.

Firstly, it is possible — and obviously optimal — to completely stabilize the output gap and inflation against demand and technology shocks. This is immediately seen by inspecting (7) and (8). A positive shock to demand, $g_t > 0$ leads to an equivalent rise in μ_t and would, in absence of any policy response, increase the output gap and thus inflation. But by raising the interest rate by $(1-\theta)^{-1}\sigma^{-1}g_t$, any effect on the output gap and thus inflation is eliminated. Likewise, if a positive technology shock hits, i.e., $y_t^n > 0$, then in absence of any policy response, the output gap decreases and creates deflation. However, as is evident, a decrease in the interest rate of $(1-\theta)^{-1}\sigma^{-1}\left(1-(1-\theta)\gamma_y\right)y_t^n$, stabilizes the output gap completely, and, therefore, also inflation. In other words, these shocks do not constitute a policy trade-off.

Secondly, it is not possible to perfectly stabilize the output gap and inflation against a cost-push shock. This also follows immediately upon inspection of (7) and (8). In the case of, e.g., a positive realization of ε_t, inflationary pressures arise in the economy. These can only be dampened through a contractionary policy reducing the output gap. The policymaker must therefore trade off the gain of the contraction in terms of lower inflation against the loss in terms of lower output. While this is straightforward, the optimal way of responding to such a shock is intricate, and of crucial importance for the results of the paper.

Figure 1 around here

Figure 1 plots the optimal path of the real interest rate following a one standard deviation positive realization of the cost-push shock in period 1. The shock is transitory (i.e., $\gamma_\varepsilon = 0$), and the parameter values used have the particular feature that no endogenous persistence is present (i.e., $\phi = \theta = 0$). (The precise parameterization of the model generating the figure is a deviation from the baseline parameter configuration described in detail in Section 4.1.) Nevertheless, it follows that interest rate policy is highly persistent, i.e., the contraction following the shock carries on for several periods. The reason for this, at first glance somewhat surprisingly feature, is simple. As mentioned, to fight inflation, the output gap has to be reduced. The effectiveness of this rests, of course, crucially on the elasticity of inflation with respect to the output gap. But as inflation is also determined by expected future inflation, a commitment to let the reduction in the output gap persist into the future reduces current inflation further as expected future inflation drops. In other words, a given reduction in current inflation can be obtained by a smaller decrease in the output gap if the drop is persistent (one may say that the monetary authority then relies on market expectations to do part of the stabilization job). Thus, the inflation-output gap trade-off is improved when policy exhibits what Woodford (1998) have termed "Optimal Monetary Policy Inertia."[12]

As will be evident in the next section, such a commitment to future contractionary policy following a positive, temporary cost-push shock is not credible. In the period after the shock, it will be optimal to let the economy return to steady state of zero inflation and output gap. This, after all, is the optimal choice when the economy is not subject to shocks, and thus highlights the time-inconsistency of the optimal plan.

3. Targeting regimes with discretionary policymaking

Having established the benchmark of precommitment, I now turn to discretionary policymaking under optimal targeting regimes. A targeting regime is understood to be an institutional set-up where the government delegates monetary policy conduct to an independent central bank who is required to minimize an assigned loss function. Moreover, the parameters of the loss function are chosen so as to minimize society's loss from the associated discretionary equilibrium.

I focus on the case where the central bank is assigned a loss function depending on the output gap, inflation and nominal income growth. More generally, the loss function takes the form

$$L^T = \mathrm{E}_0 \sum_{t=1}^{\infty} \beta^{t-1} \left[\lambda \left(y_t - y_t^n \right)^2 + (1+f)\, \pi_t^2 + \psi n_t^2 \right], \tag{10}$$

where

$$n_t \equiv \pi_t + y_t - y_{t-1},$$

is the rate of nominal income growth.[13] The parameters f and ψ are chosen at the stage

[12] Woodford was the first to clarify this phenomenon in a model like the one adopted here with $\phi = \theta = 0$. He, however, does not consider cost-push shocks, but only demand and technology shocks (i.e., μ_t shocks, interpreted as shocks to the "natural rate of interest"). In his model, these shocks involve a policy trade-off as nominal interest rate fluctuations *per se* (*not* changes) are disliked by society.

[13] As y_t is output deviations from trend output, n_t is, of course, nominal income growth relative to real

of "institutional design" and will under various restrictions on their values define various targeting regimes. Note that the parameters are constrained to be constant. This is because, as discussed in Beetsma and Jensen (1999), a monetary institutional set-up whose characteristics are constant across business cycles are much less subject to the McCallum (1995) critique of the theories of monetary delegation. In a nutshell, McCallum states that a government handing over monetary control to a central bank with some loss function different from society's, at some point has the incentive to undo the assignment and take over control of policy itself (or, alternatively and equivalently, change the loss function into that of society's). If the loss function was institutionally allowed to be changed regularly according to the state of the economy, then this incentive would almost be encouraged to lead to action. Therefore, only state-independent loss functions are allowed. Furthermore, it is assumed that sufficiently strong institutional constraints prevent the government from ever changing them (i.e., some costs of changing institutions are present; see, e.g., Lohmann, 1992, and Jensen, 1997, on this issue within models of the Barro and Gordon, 1983, type).

The targeting regimes to be considered are the following. First, *pure discretion* is the case of $f = \psi = 0$. Then, the central banker shares society's loss function, and it therefore corresponds to a case where a benevolent government conducts discretionary monetary policy by itself. It will mainly serve as a "worst case" scenario, enabling one to judge the benefits of precommitment, and, more importantly, the benefits of adopting alternative targeting regimes.

Secondly, IT is defined as the case where $-1 < f < \infty$, $\psi = 0$. That is, the central bank is required to aim at price stability, but not at all costs in terms of the output gap. It thus represents the case dubbed "flexible" IT by Svensson (1999a). This definition of IT seems to be in accordance with the understanding of its real world practitioners, who generally do not ignore the real side of the economy, see, e.g., King (1997). Note that when $f > 0$, the central bank is required to put more weight on inflation relative to the output gap in comparison with the social welfare function, i.e., it is supposed to be "conservative" in the terminology of Rogoff (1985).

Third, NIGT is defined as the case where $f = -1$, $0 < \psi < \infty$. Hence, the central banker is required to care for nominal income growth stability, disregard inflation variabil-

trend output growth (Log of actual real output is given by $y_t^a = y_t + y_t^t$, where y_t^t is log of trend output. It thus follows that actual nominal income growth is $\pi_t + y_t^a - y_{t-1}^a = \pi_t + y_t + y_t^t - \left(y_{t-1} + y_{t-1}^t\right) = \pi_t + y_t - y_{t-1} + y_g$, where y_g is real trend output growth. Hence, $\pi_t + y_t - y_{t-1}$ equals $\pi_t + y_t^a - y_{t-1}^a - y_g$, i.e., nominal income growth net of real trend output growth.) Targeting n_t at zero is therefore equivalent of targeting nominal income growth at the rate of real output trend growth. In the long run this is consistent with an inflation target of zero which is also implied by L^T.

ity, but *not* neglect variations in the output gap. This seems as a natural definition of what NIGT should be in reality. As a central banker operating under IT is assumed not to ignore the output gap, I see no particular reasons for why a central banker under NIGT should do so. Such a situation would correspond to "strict" NIGT and strikes, of course, a socially inefficient balance between inflation and output gap volatility; just as "strict" IT does.[14]

Fourth, a *combination regime* is defined as $-1 < f < \infty$, $0 < \psi < \infty$. In this case, the central banker is required to balance the volatility of the output gap, inflation and nominal income growth appropriately. Some may argue that such a regime would be undesirable as it could be more and more difficult for the public to assess the success of monetary policy, the more targets are supposed to be met. While such arguments certainly appear intuitive, they have not received much formal justification. (Compared to many other areas of legislation, for example, social security systems that typically have several objectives, a monetary regime where the volatility of merely three macroeconomic variables is weighted against each other appears rather simple.) In any case, examination of the combination regime serves to complement the comparison of inflation and NIGT because it provides information on how strong emphasis either variable should achieve *if* a combination regime is feasible at all.

To solve the model under discretion, it is again formulated in state-space form (the solution is provided for the combination regime, as the other regimes follow as special cases). Hence, define $\widehat{\mathbf{Z}}_t \equiv \left[\widehat{\mathbf{X}}' \quad \widehat{\boldsymbol{\chi}}_t'\right]'$ as the (column) vector of predetermined ($\widehat{\mathbf{X}}_t$) and forward-looking ($\widehat{\boldsymbol{\chi}}_t$) variables, with

$$\widehat{\mathbf{X}}_t \equiv [g_t \quad y_t^n \quad \varepsilon_t \quad y_{t-1} \quad \pi_{t-1}]', \quad \widehat{\boldsymbol{\chi}}_t \equiv [y_t \quad \pi_t]'.$$

Note that because the loss function now involves output, and not just the output gap, the state-vector is formulated in terms of output. The dynamics of the model are

$$\begin{bmatrix} \widehat{\mathbf{X}}_{t+1} \\ \mathrm{E}_t \widehat{\boldsymbol{\chi}}_{t+1} \end{bmatrix} = \widehat{\mathbf{A}} \begin{bmatrix} \widehat{\mathbf{X}}_t \\ \widehat{\boldsymbol{\chi}}_t \end{bmatrix} + \widehat{\mathbf{B}} i_t + \begin{bmatrix} \widehat{\boldsymbol{\zeta}}_{t+1} \\ \mathbf{0}_{2\times 1} \end{bmatrix}, \tag{11}$$

[14]Some recent literature has discarded NIGT as a relevant monetary policy strategy, indeed under the interpretation that it is "strict"; cf. Clarida et al. (1999a, Section 7.2) and Svensson (1999a, Section 4.2). One could, however, just as easy discard the relevance of IT if it is understood to be strict as well. Guender (1999) compares strict nominal income targeting and strict IT in a model similar to the present one.

where

$$\widehat{\mathbf{A}} \equiv \begin{bmatrix} \gamma_g & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \gamma_y & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \gamma_\varepsilon & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ -\frac{1}{1-\theta} & -\frac{\sigma\kappa}{\beta} & \frac{\sigma}{(1-\phi)\beta} & -\frac{\theta}{1-\theta} & \frac{\sigma\phi}{(1-\phi)\beta} & \frac{1+(1-\theta)\sigma\beta^{-1}\kappa}{(1-\theta)} & -\frac{\sigma}{(1-\phi)\beta} \\ 0 & \frac{\kappa}{\beta} & -\frac{1}{(1-\phi)\beta} & 0 & -\frac{\phi}{(1-\phi)\beta} & -\frac{\kappa}{\beta} & \frac{1}{(1-\phi)\beta} \end{bmatrix},$$

$\widehat{\mathbf{B}} \equiv \begin{bmatrix} \mathbf{0}_{1\times 5} & \sigma & 0 \end{bmatrix}'$, and $\widehat{\boldsymbol{\zeta}}_{t+1} \equiv \begin{bmatrix} \zeta_{t+1}^g & \zeta_{t+1}^y & \zeta_{t+1}^\varepsilon & \mathbf{0}_{1\times 2} \end{bmatrix}'$. It follows that $\lambda (y_t - y_t^n)^2 + (1+f)\,\pi_t^2 + \psi n_t^2 = \widehat{\mathbf{Z}}_t' \widehat{\mathbf{Q}} \widehat{\mathbf{Z}}_t$ where

$$\widehat{\mathbf{Q}} \equiv \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \lambda & 0 & 0 & 0 & -\lambda & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \psi & 0 & -\psi & -\psi \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -\lambda & 0 & -\psi & 0 & \lambda+\psi & \psi \\ 0 & 0 & 0 & -\psi & 0 & \psi & 1+f+\psi \end{bmatrix}.$$

The central bank's decision problem amounts to solving the linear-quadratic problem

$$\hat{J}\left(\widehat{\mathbf{X}}_1\right) = \min_{\{i_t\}_{t=1}^{\infty}} \mathrm{E}_1 \left[\sum_{t=1}^{\infty} \beta^{t-1} \widehat{\mathbf{Z}}_t' \widehat{\mathbf{Q}} \widehat{\mathbf{Z}}_t\right],$$

where the minimization is subject to (11) taking as given $\widehat{\mathbf{X}}_1$. The solution is derived under the assumption that central bank cannot precommit to any policy path beforehand, but rather re-optimizes each and every period (the solution thus characterizes a Markov-perfect equilibrium). The numerical solution method is outlined in Appendix B, and the solution's associated equilibrium dynamics, evolution of the interest rate, and unconditional covariance matrix of $\widehat{\mathbf{Z}}_t$, are, respectively, given by (B.2), (B.3), and (B.5). Appendix C demonstrates how to translate the solution into the value of society's loss, see (C.1).

To establish the *optimal* targeting regimes (pure discretion is, of course, simple, as it just requires setting $f = \psi = 0$), I have for each targeting regime minimized society's loss with respect to the relevant parameters. In all cases this has been performed numerically by grid search where the parameters f and/or ψ (whenever relevant) are varied within the relevant ranges with a grid of 0.025. Some experimentation showed that a finer grid led to negligible improvements in the optimal value of society's loss.[15]

The main qualitatively characteristics of the targeting regimes are now provided. As under precommitment, the demand shock poses no trade-off in policymaking under either regime. The interest rate can always be adjusted so as to neutralize any effects on the output gap, and hence inflation and nominal income growth. As for technology shocks, the same argument applies for IT as under precommitment. With NIGT, however, a complete stabilization of the output gap would be associated by higher output, and thus higher nominal income growth. The optimal choice will thus be a slightly less expansive policy, which in effect leads to an inefficiency in output gap and inflation stabilization from society's viewpoint. This disadvantage of NIGT in dealing with shocks that do not constitute a policy trade-off for society is further discussed in Section 4.1.

The main qualitative difference between NIGT and IT arises when the economy is hit by a cost-push shock. To facilitate comparison with the description of the precommitment solution, a case is examined where a temporary shock hits, and where the economy exhibits no endogenous persistence. For the cases of pure discretion and optimal IT (which coincide for this special case; see Section 4.3 for an explanation), Figure 2 shows the time-consistent pattern of the real interest rate, inflation and the output gap. A comparison with the figure for precommitment reveals a marked difference. As the central bank under discretion cannot credible commit to future contractionary policy in order to attain a more favorable inflation-output gap trade-off, it has no other choice than to just "react within the period;" in the next period there is no shock and it is optimal to let the economy be in steady state. So, optimal, but time consistent, monetary policy fails to deliver the inertial interest rate behavior that is desirable for society.

Figures 2-3 around here

Consider then the optimal NIGT regime under the same experiment. Figure 3 illustrates the time-consistent paths of the real interest rate, inflation and output gap. It is immediate that the contraction triggered by the cost-push shock persists into the future even though the shock is temporary. This is beneficial for society as explained before, as it reduces expectations about future inflation, which helps fight current inflation. The

[15] A finer grid would also make the simulations rather time consuming. For example, with the chosen grid, a search over the intervals $-1 \leq f \leq 1$ and $0 \leq \psi \leq 2$ requires over $6,500$ computations, each involving the determination of the discretionary solution and the associated societal loss. Even though the algorithms determining these solutions work quite fast ($1-2$ seconds in sum), such a search takes well over two hours.

reason for this inertial behavior is straightforward. When the central bank observes the realization of ε, the associated increase in nominal income growth induces it to contract monetary policy. This reduces the output gap and output below their steady-state values. In the following period the economy settles back into the steady state, and the central bank, operating under discretion, re-optimizes. With the economy back in steady state and past period's output below steady state, it follows trivially that nominal income growth is above target. The optimal, time-consistent policy is therefore to contract again putting output and inflation below steady state (so, in correct anticipation of this, agents' expectations about period 2 deflation help reduce period 1 inflation). This process continues until nominal income growth settles down.

Targeting nominal income growth is thus a manner by which the central bank is committed, under discretion, to inertial behavior. A behavior that improves the inflation-output gap trade-off and may result in policymaking that is preferable for society compared to that arising from IT.

4. Optimal targeting regimes: comparisons under various parameter constellations

To get a firmer grip on the relative performance of inflation and NIGT, the associated losses of society are now compared for a number of parameter constellations. These comparisons will also involve the losses from the precommitment solution, pure discretion and the combination regime. First, the results from a baseline parameter set are reported, and subsequently results are reported where the structural parameters of the model are varied relative to this baseline.

4.1. The baseline parameter values

The choice of baseline parameter values for the model is not an easy task as the literature (on U. S. data) contains strongly conflicting views on many of these. So in most cases, "compromise values" are used, and no presumption is made about having the model match business cycle data accurately. It has merely been an aim that the model's properties with respect to the volatility of the nominal interest rate, output and inflation are not completely unreasonable across regimes. In any case, the ensuing sensitivity analyses illustrate the main points of the paper, which, after all, are basically theoretical, not empirical.

Concerning aggregate demand, (1), the results of Fuhrer (1998) suggest that a value of $\theta = 0.5$ is not unreasonable. Concerning the real interest rate sensitivity of demand,

$\theta = 0.5, \quad \phi = 0.3, \quad \sigma = 1.5, \quad \kappa = 0.07, \quad \lambda = 0.25,$
$\sigma_g = 0.015, \quad \sigma_y = 0.005, \quad \sigma_\varepsilon = 0.015,$
$\gamma_g = 0.3, \quad \gamma_y = 0.97, \quad \gamma_\varepsilon = 0.00.$

Table 1: Baseline parameter configuration

estimates range from very high values (Rotemberg and Woodford, 1997, report a value above 6) to very low ones (McCallum and Nelson, 1999b, report a value of around 0.2). A compromise value, with a prior attached to the lower estimate, yielding a reasonable standard deviation of the interest rate in the model, is 0.75, which given $\theta = 0.5$ fixes σ at 1.5.

With respect to the aggregate supply equation, (3), the degree of persistence in price setting (and thus, by implication, the importance of forward-looking behavior) is subject to controversy. Fuhrer (1997) essentially rejects statistically any importance of forward-looking behavior (suggesting $\phi = 1$), but acknowledges, however, that inflation dynamics without forward-looking behavior are implausible. In contrast, Galí and Gertler (1999) conclude that persistence is rather unimportant and that an exclusively forward-looking inflation equation is a reasonable first approximation to data. Estimates of Roberts (1997, 1998) suggest a value of ϕ in the neighborhood of 0.4. As the focus in this paper is the implications of forward-looking behavior, I choose a value of $\phi = 0.3$. Concerning the sensitivity of inflation to the output gap, evidence is also mixed. The results of Rotemberg and Woodford (1997) suggest a value around 0.025; a magnitude also supported in Estrella and Fuhrer (1998). Roberts (1995) is more in line with a value of 0.3. I choose the sensitivity to 0.05, and given that $\phi = 0.3$, this fixes κ at approximately 0.07. In line with virtually all literature, I set $\beta = 0.99$.

The literature contains some implicit estimates of society's weight on output gap fluctuations relative to inflation fluctuation in its loss function. Woodford (1998) reports a very low value around 0.05, whereas Broadbent and Barro's (1997) results indicate a value of one third. I attach most weight to this result and set $\lambda = 0.25$.

Of main importance are the standard deviations of the stochastic disturbances of the model. I set $\sigma_g = 0.015$ and $\gamma_g = 0.3$ (this is close to values reported by McCallum and Nelson, 1999b). As regards the technology shock, it is assumed that innovations have smaller standard deviation (as also assumed by Svensson, 1999b) but that they are very persistent; $\sigma_y = 0.005$ and $\gamma_y = 0.97$ (hence, the unconditional standard deviation of y^n is above 0.02). The cost-push shock is assumed to have standard deviation as demand shocks, but to be transitory only: $\sigma_\varepsilon = 0.015$ and $\gamma_\varepsilon = 0$ (quantitatively, this standard deviation is not in stark contrast to what is implied by the results of Roberts, 1997). The

	Precom-mitment	Pure Dis-cretion	IT	NIGT	Combina-tion regime
Society's loss ($\times 100$)	4.3087	5.1697	5.1183	4.6422	4.6422
Optimal f	—	—	0.625	—	-1.000
Optimal ψ	—	—	—	0.850	0.850
S.d. of π (percent)	1.9546	2.2457	2.1894	1.9385	1.9385
S.d. of x (percent)	1.4352	0.7405	1.1566	1.8960	1.8960
S.d. of y (percent)	2.5080	2.1860	2.3596	2.6831	2.6831
S.d. of i (percent)	2.3182	2.6381	2.8703	2.5015	2.5015

Table 2: Results for baseline parameter configuration

baseline parameter configuration is summarized in Table 1.

4.2. Results for the baseline parameter values

Table 2 reports simulation results for the baseline parameter values. It shows society's loss under the five monetary policy scenarios: precommitment, pure discretion, optimal IT, optimal NIGT and the optimal combination regime. In addition, the optimal values of the central bank's loss function parameters under the three latter scenarios are reported. Finally, the percentage unconditional standard deviations of inflation, the output gap, output and the nominal interest rate are reported for each policy regime.[16]

First, the first two columns confirms that pure discretionary monetary policy is inferior to precommitment even though there is no inflation bias under discretion. The reason is the impossibility of adhering to an inertial policy under discretion as explained in Section 3. The result of this is higher inflation variability. The lower variability of the output gap, cannot counteract this inflation volatility loss (remember that output gap fluctuations are only weighted by a quarter). To illustrate the magnitude of the welfare gain from precommitment, the loss of moving from precommitment to pure discretion is in welfare terms equivalent of a permanent increase in inflation of around 0.9 percent. Alternatively, it is equivalent to a permanent drop in the output gap by almost 2 percent.[17] The precommitment responses of the real interest rate, inflation and output gap towards a one standard deviation cost-push shock under the baseline configuration are depicted in Figure 4. The equivalent responses are depicted for the case of optimal IT in Figure 5.

[16]For the case of all variables, except the interest rate, these standard deviations are the exact ones as derived in Appendices A [equation (A.9)] and B [equation (B.5)]. For the interest rate, the results are simulated standard deviations, derived as the average of 500 runs of each $3,000$ periods.

[17]To see this, note that the difference in losses, (not multiplied by 100) is 0.0086. A permanent inflation rate of c percent yielding a loss of this magnitude should satisfy $0.0086 = [1/(1-\beta)](c/100)^2$, which under the baseline becomes $0.86 = c^2$. Similarly, a permanent output gap of c percent yielding this loss should satisfy $0.0086 = \lambda[1/(1-\beta)](c/100)^2$, which under the baseline becomes $0.86/0.25 = c^2$.

Under IT, it is optimal to appoint a conservative central banker ($f > 0$) because even with a transitory cost-push shock, the endogenous persistence in price setting causes the shock to have prolonged effects on inflation. By being more conservative in attitude, a more contractive policy is directed towards the aftermath of the shock. This dampens, in the period the shock hits, expectations about future inflation and thus leads to a more favorable inflation-output gap trade-off.[18] A related finding appears in Clarida et al. (1999a), who consider simple rules where policy is a constrained function of the cost-push shock. They also demonstrate that a more conservative central banker is favorable for the reasons just described (in absence of endogenous inflation persistence, their result requires persistence in the process for the cost-push shock). Note however, that the welfare gain of IT with an optimally chosen conservative central banker is limited: there are, e.g., only small welfare differences between pure discretion and optimal IT.

Figures 4-6 around here

As seen by the fourth column of Table 2, the gain from an optimally designed NIGT regime is larger. Going from pure discretion towards this regime, brings the societal loss much closer towards the precommitment loss than does IT. The gain is of a magnitude equivalent of a permanent inflation rate of around 0.75 percent or a permanent output gap of nearly 1.5 percent. Figure 6 shows the responses of the real interest rate, inflation and output gap following a cost-push shock. Note the rough similarity of this figure with its counterpart under precommitment, Figure 4.

Finally, it is seen from Table 2 that if it is feasible to have the central banker target both inflation and nominal income growth (in addition to the output gap), the optimal combination regime is one where the inflation target should play approximately *no* role at all.[19] The reason for the superiority of optimal NIGT is, as explained in Section 3, its ability of inducing optimal inertial interest rate behavior.

Figure 7 around here

A downside of NIGT is that it fails to insulate the economy from technology shocks, cf. Section 3. This is illustrated here by Figure 7, depicting the responses of the real interest rate, inflation and output gap towards a one standard deviation positive innovation to the

[18] Quite intriguingly, conservatism thus serves to *improve* macroeconomic stabilization under IT. This runs counter to Rogoff's (1985) original analysis where conservatism *distorts* stabilization.

[19] The qualifier "approximately" refers to the fact that the grid search method of finding the optimal targeting regimes implies that on cannot rule out that the *exact* optimal combination regime involves a value of f between -1 and -0.975. But this means that the optimal weight on the inflation objective can at most be 0.025, which is indeed of trivial magnitude compared to the optimal weight on the nominal income growth target (0.85).

	Precom-mitment	Pure Dis-cretion	IT	NIGT	Combina-tion regime
Society's loss (×100)	14.1661	16.7975	15.3159	14.5463	14.1936
Optimal f	—	—	1.100	—	0.400
Optimal ψ	—	—	—	1.125	0.625
S.d. of π (percent)	2.8294	3.6390	3.0170	3.0208	2.8285
S.d. of x (percent)	5.0482	3.9553	5.0690	4.7720	5.0606
S.d. of y (percent)	5.4509	4.4580	5.4779	5.1577	5.4402
S.d. of i (percent)	3.6437	4.7011	4.9286	3.5045	3.6443

Table 3: Deviation from baseline: More persistence in price setting ($\phi = 0.6$ and $\kappa = 0.125$)

process for the technology shock. As evident, the central banker is unable to neutralize the output gap completely as this conflicts with the associated increase in nominal income growth. It will therefore be optimal to conduct an only mildly expansive policy, which allows the output gap to fall. This fall, however, puts a downward pressure on inflation and thus nominal income growth. In equilibrium, the conflict between stabilizing the output gap and nominal income growth is therefore somewhat limited. This explains why it, under the baseline parameterization, does not outweigh the benefits of NIGT in terms of responding to shocks that do constitute a trade-off for society (note also that the inflation effects of the technology shock are limited, and that the output gap effects die out rather quickly).

In the following sub-section sensitivity analyses are performed in order to further highlight which properties of the model tend to favor NIGT over IT, and which do not.

4.3. Deviations from baseline parameters

As mentioned, all sensitivity analyses take the form of varying one structural parameter relative to baseline. One class of sensitivity analyses is rather uninteresting and will only briefly be mentioned here. It concerns variations in the parameters of the aggregate demand function, (1). It follows that any value of the demand shock and any value of lagged output can be perfectly offset under any policy regime (this hinges on the fact that policy can respond to contemporaneous variables). Sensitivity analyses involving changes in the persistence of demand, θ, and characteristics of the process for g_t will therefore reveal no effects on the equilibrium outcomes for the output gap, inflation, and society's loss. The only difference across parameter changes will be in terms of interest rate variability. Likewise, any change in σ affects only the magnitude of the interest rate change needed to achieve the desired effect on aggregate demand. Of more importance are the parameter

	Precommitment	Pure Discretion	IT	NIGT	Combination regime
Society's loss (×100)	2.0455	2.2277	2.2277	2.2173	2.2173
Optimal f	—	—	0.000	—	-1.000
Optimal ψ	—	—	—	0.125	0.125
S.d. of π (percent)	1.3957	1.4851	1.4851	1.4712	1.4712
S.d. of x (percent)	0.6547	0.2970	0.2970	0.4597	0.4597
S.d. of y (percent)	2.1584	2.0781	2.0781	2.0634	2.0634
S.d. of i (percent)	2.1069	2.1329	2.1329	2.1400	2.1400

Table 4: Deviation from baseline: No endogenous persistence at all ($\phi = 0.0$, $\theta = 0.0$, $\kappa = 0.05$ and $\sigma = 0.75$)

changes presented in the remainder of this sub-section.

First, the importance of endogenous inflation persistence is assessed. Table 3 presents a variation of the baseline where persistence is doubled, i.e., where $\phi = 0.6$ (to isolate the effect to a changed weight on the importance of lagged inflation versus expected future, κ is changed so that the elasticity of inflation with respect to the output gap is kept constant at 0.05). This has the consequence that the benefits of optimal IT relative to pure discretion are stronger than in baseline. The reason is that when temporary shocks have longer lasting effects, the ability to signal future contractive behavior by appointing a conservative central banker becomes more valuable (note also that the optimal degree of conservativeness is higher than in baseline). By the same token, the benefits of optimal NIGT are also larger (and the optimal value of ψ is also higher compared to baseline). The improvement of going from pure discretion towards optimal NIGT is equivalent in welfare terms of a permanent inflation rate (output gap) change of around 1.5 (3.0) percent. Hence, the more persistent inflation behaves, the stronger is the case for NIGT relative to IT. It is, however, as explained below, important that expected future inflation continues to play a non-negligible role in inflation determination.[20]

Table 4 then considers the other extreme, where price setting is purely forward looking, i.e., $\theta = 0$ (and κ is adjusted to maintain an inflation elasticity of the output gap of 0.05). In this variation, it is also assumed that there is no endogenous persistence in demand (this is without consequences for the results, but is included as the table then presents the parameter deviation applied in Figures 1-3). As expected, IT cannot improve over pure discretion: since its only virtue is to secure a commitment to future economic developments, nothing is gained when the impact of the cost-push shock is confined to be transitory. This

[20] Note by Table 3 that if a combination regime is feasible, it will now, in contrast with baseline, be optimal to attach weight to both the inflation and nominal income growth objective. The welfare improvement compared to optimal NIGT alone, however, is not overwhelming.

	Precom-mitment	Pure Dis-cretion	IT	NIGT	Combina-tion regime
Society's loss (×100)	3.4573	4.4368	4.3554	3.5674	3.5674
Optimal f	—	—	0.500	—	-1.000
Optimal ψ	—	—	—	1.200	1.200
S.d. of π (percent)	1.6647	2.0105	1.8976	1.6256	1.6256
S.d. of x (percent)	1.6775	1.2676	1.7445	1.9373	1.9373
S.d. of y (percent)	2.6541	2.4160	2.6969	2.7102	2.7102
S.d. of i (percent)	2.3219	2.8969	3.2305	2.3920	2.3920

Table 5: Deviation from baseline: Higher inflation sensitivity to output gap ($\kappa = 0.142$)

	Precom-mitment	Pure Dis-cretion	IT	NIGT	Combina-tion regime
Society's loss (×100)	4.8573	5.4189	5.4010	5.2966	5.2966
Optimal f	—	—	0.700	—	-1.000
Optimal ψ	—	—	—	0.375	0.375
S.d. of π (percent)	2.1346	2.3222	2.3033	2.2286	2.2286
S.d. of x (percent)	1.1560	0.3904	0.6551	1.1694	1.1694
S.d. of y (percent)	2.3592	2.0934	2.1585	2.2821	2.2821
S.d. of i (percent)	2.3293	2.4916	2.6145	2.5473	2.5473

Table 6: Deviation from baseline: Lower inflation sensitivity to output gap ($\kappa = 0.035$)

will, on the other hand, be the case under nominal optimal income growth targeting, which again is seen to yield a lower societal loss than IT. For this case of no persistence, however, the magnitude appears trivial. So, taken together, these results of Tables 3-4 suggest that the more persistent is shocks to inflation, the more preferable is NIGT. Its feature of being a credible commitment to future disinflationary behavior, makes it superior to IT in terms of stabilizing inflation.

Note, however, that since the main virtue of NIGT relative to IT arises due to forward-looking price setting, it should come as no surprise that if inflation is mainly determined by history, the case for nominal income growth vanishes. For example, in the limiting case of $\phi = 0.99$, expected inflation plays only an infinitesimal role for inflation determination. Then, there are no time inconsistency problems, and society's losses from pre-commitment and pure discretion become approximately identical. IT (with $f \simeq 0$) is then obviously preferable.

Tables 5 and 6 show the implications of increasing, respectively, decreasing the sensitivity of inflation to the output gap. The changes are, taken into account the baseline value of $\theta = 0.3$, such that the high elasticity is 0.1 and the low is 0.025. It turns out,

	Precom- mitment	Pure Dis- cretion	IT	NIGT	Combina- tion regime
Society's loss ($\times$100)	3.7883	4.7704	4.6940	3.8408	3.8408
Optimal f	—	—	0.550	—	-1.000
Optimal ψ	—	—	—	1.225	1.225
S.d. of π (percent)	1.7793	2.1196	2.0254	1.7609	1.7609
S.d. of x (percent)	2.5358	1.6926	2.4483	2.7548	2.7548
S.d. of y (percent)	3.2650	2.6636	3.1976	3.2928	3.2928
S.d. of i (percent)	2.4288	3.2315	3.8246	2.4671	2.4671

Table 7: Deviation from baseline: Lesser societal concern for output gap ($\lambda = 0.1$)

within this parameter range, that the more sensitive to the output gap is inflation, the more favorable is NIGT relative to IT. One explanation is based on the fact that with a better societal inflation-output gap trade-off, any regime will perform better (note that the losses are lowest in all regimes for the high value of κ). Therefore, the previously described benefits of NIGT can be attained at an even lower cost. Indeed, the welfare difference between IT and NIGT amounts to a permanent percentage change in inflation (output gap) of around 0.9 (1.75) when $\kappa = 0.142$, while the corresponding numbers are only around 0.3 (0.65) when $\kappa = 0.035$. Put in opposite terms, when the trade-off reaches the limit where the output gap has virtually no effect on inflation, any regime will perform equally bad in terms of stabilizing inflation.

The relative performance of regimes is, however, not monotonic with respect to changes in κ. If the elasticity of inflation with respect to output, e.g., takes on rather high values, IT becomes preferable. This is because with a high value of κ, technology shocks come to play a much more important role for inflation determination, thereby aggravating the inefficiency of NIGT. Also, changes in the output gap become very powerful in stabilizing inflation which, in turn, reduces the importance of low expected future inflation as a stabilization device; a device that is the virtue of NIGT (the precommitment solution also exhibits very little interest rate inertia in that case).[21] In the (only illustrative) limit of $\kappa \to \infty$, any shock to inflation can be neutralized by an infinitesimal change in the output gap, and cost-push shocks will no longer present a trade-off for monetary policy. In consequence, it is best to adopt a targeting regime where the central bank's preferences are aligned with society's.

Before examining the role of the distributional characteristics of the shocks, I report

[21] For the case of an inflation elasticity with respect to the output gap of 0.3, used by Clarida et al. (1999b) (implying $\kappa = 0.429$), nominal income growth targeting is still preferable, however. (The societal loss ($\times$100) is 1.9617, while it is 2.2076 under optimal inflation targeting.)

	Precommitment	Pure Discretion	IT	NIGT	Combination regime
Society's loss (×100)	5.3333	5.5026	5.5006	5.5015	5.5005
Optimal f	—	—	0.725	—	0.525
Optimal ψ	—	—	—	0.200	0.025
S.d. of π (percent)	2.2889	2.3475	2.3454	2.3459	2.3454
S.d. of x (percent)	0.1141	0.0199	0.0342	0.0324	0.0341
S.d. of y (percent)	2.0599	2.0570	2.0570	2.0546	2.0567
S.d. of i (percent)	2.3255	2.3543	2.3573	2.3529	2.3564

Table 8: Deviation from baseline: "Extreme" societal concern for output gap ($\lambda = 10$)

sensitivity analyses concerning society's attitude towards inflation, i.e., variations in the parameter λ. Tables 7 and 8 show the results. They reveal that if society cares a lot about inflation variability relative to output variability, i.e., if λ is small, the case for NIGT is strengthened relative to the baseline scenario. The gain of going from a regime of pure discretion towards NIGT amounts to a permanent percentage change in inflation (output gap) of almost 1.0 (3.0). The corresponding numbers associated with an adoption of an IT regime are only 0.30 (0.9). The reason is again that NIGT is better at stabilizing inflation than is IT. This ability will, of course, be more valued by a society caring relatively much about inflation stability. By reverse argumentation it then follows that a society that cares predominantly by movements in the output gap may favor IT over NIGT. This is indeed the case as illustrated by Table 8 where λ takes on the rather extreme value of 10. In that case, society would favor IT. Note, though, that the welfare differences between the two targeting regimes are trivial.

Now, the implications of changes in the properties of the processes of technology and cost-push shock, (4) and (5), respectively, are considered. As mentioned previously, the inefficiency created by NIGT is the inability of insulating the economy from technology shocks. Table 9 therefore show the deviation from baseline where the standard deviation of ζ_t^y is raised to that of the other shocks of the model, i.e., to 0.015. Note that this will cause the unconditional standard deviation of technology shocks to exceed 6 percent. Even with this rather high volatility of technology shocks, NIGT outperforms IT, although, of course, the quantitative gain in welfare terms is reduced compared with the baseline. If σ_y is instead raised to 0.03 (implying an unconditional standard deviation of technology shocks of over 12 percent), *then* IT would have been superior (these results are not reported). The welfare loss of NIGT, however, raises only to 5.3484, which is rather little in light of the considerable volatility of technology shocks (the loss under IT is, as explained previously,

	Precom- mitment	Pure Dis- cretion	IT	NIGT	Combina- tion regime
Society's loss (×100)	4.3087	5.1697	5.1183	4.9242	4.9217
Optimal f	—	—	0.625	—	-0.675
Optimal ψ	—	—	—	0.550	0.475
S.d. of π (percent)	1.9546	2.2457	2.1894	2.0339	2.0365
S.d. of x (percent)	1.4352	0.7405	1.1566	1.7896	1.7735
S.d. of y (percent)	6.3348	6.2145	6.2777	6.0682	6.0957
S.d. of i (percent)	2.5144	2.8145	3.0340	2.5308	2.5684

Table 9: Deviation from baseline: Higher variance of technology shocks ($\sigma_y = 0.015$)

	Precom- mitment	Pure Dis- cretion	IT	NIGT	Combina- tion regime
Society's loss (x100)	10.4706	14.0952	13.6341	11.3312	11.3312
Optimal f	—	—	1.075	—	-1.000
Optimal ψ	—	—	—	1.275	1.275
S.d. of π (percent)	2.9292	3.7036	3.4723	2.8363	2.8363
S.d. of x (percent)	2.8398	1.3510	2.5673	3.6741	3.6741
S.d. of y (percent)	3.5064	2.4607	3.2896	4.1204	4.1204
S.d. of i (percent)	2.8969	3.8418	4.4032	3.1110	3.1110

Table 10: Deviation from baseline: Persistence in cost-push shocks ($\gamma_\varepsilon = 0.30$)

invariant with respect to the process of these shocks).[22]

Then consider the case where some persistence is introduced into the process for the cost-push shock. This is depicted in Table 10 where $\gamma_\varepsilon = 0.30$. In light of the preceding discussions it should come as no surprise that the case for NIGT becomes stronger relative to baseline. Indeed, going from pure discretion towards NIGT results in a welfare gain equivalent in a permanent percentage change in inflation (output gap) of around 1.7 (3.3). Adopting an IT regime, on the other hand, provides a corresponding gain with numbers in the neighborhood of 0.8 (1.4). Note that in comparison with baseline, under both optimal targeting regimes the output gap should receive relatively lesser attention. This is for the reasons described previously: with more persistence in inflation following a shock, it requires a more firm commitment to "conservative" policies in the future to better cope

[22] Another sensitivity analysis, not reported, involved raising the persistence of technology shocks to $\gamma_y = 0.99$. As this only increases their unconditional standard deviation to around 3.5 percent, the results were "between" the baseline and those of Table 9. Also, of course, in the limiting case of $\sigma_y^2 = 0$, the relative performance of NIGT improved; the welfare loss fell to 4.5995. This is not much lower than under the baseline case, and suggests that the inefficiency of NIGT only starts to "bite" at very high variances of technology shocks.

with current inflation (hence, just raising the standard deviation of the cost-push shock does not change the optimal value of f under IT). But even though that IT improves over pure discretion when shocks to inflation persists, Table 10 stresses that NIGT becomes even more favorable, the more persistent are the effects of shocks to inflation.

One may therefore conclude that the results portrayed in Tables 3 and 10 point to the paradox that IT is increasingly inferior in coping with inflation volatility, the more persistent are the effects of shocks to inflation. This holds no matter whether persistence is endogenous or caused by autoregressive behavior of cost-push shocks (albeit in the case of endogenous persistence, it should not be of a magnitude obliterating forward-looking aspects of price setting; cf. the previous discussion).

5. Discussions

5.1. Implications of misinterpretation of targeting regime

Apart from sensitivity analyses, another way of assessing the desirability of NIGT, is by examining the sensitivity of society's equilibrium loss to changes in the delegation parameter ψ. Realistically, one may expect some ambiguity in the way the weights on macroeconomic variables are written into the guidelines or legislation for monetary policy conduct. I.e., even though optimal values can be identified in principle, they may be impossible to implement precisely.

To gauge the associated welfare consequences, recall that under the baseline parameter configuration, the optimal value of $\psi = 0.85$ yields a societal loss of 4.6422. Consider now a case where the central bank erroneously acts as if the weight was, respectively, half or double as the optimal. In turns out that for $\psi = 0.425$ ($\psi = 1.7$) society's loss would be 4.7513 (4.7345). Hence, even with such large (and *permanent*) misinterpretations of the policy regime, NIGT is preferable to IT. In fact, under the baseline the central bank should act as if $\psi > 5.5$ or $0 < \psi < 0.13$ before NIGT is inferior to optimal IT. This suggests that a substantial misinterpretation of the intended NIGT regime is required before it is inferior to IT.

5.2. State-contingent nominal income growth targeting

In Section 3 it was argued that only state-independent targeting regimes are likely to be feasible. It is, however, in some instances a matter of interpretation whether a regime is state independent or not. For example, those considered so far involve a constant target value for the output gap. This, however, is the equivalent of targeting output at the natural rate, which is a time-varying variable. Likewise, a constant target value for inflation is the equivalent of a state-contingent target for the price level.

Consider the following thought experiment. If output gap targeting is feasible, the value of the natural rate of output must be known (or, in real-life terms, a good estimate is available). Therefore y_t^n could, in principle, also serve as a target value for other macroeconomic variables. Indeed, it turns out that if nominal income growth is targeted at the *growth* rate of y_t^n, the inefficiency of NIGT in terms of responses towards technology shocks will be smaller. To see this, note that the central banker's per-period loss function in this case would be

$$\begin{aligned} & \lambda \left(y_t - y_t^n\right)^2 + \psi \left(n_t - \left(y_t^n - y_{t-1}^n\right)\right)^2 \\ = \;& \lambda \left(y_t - y_t^n\right)^2 + \psi \left(\pi_t + \left(y_t - y_t^n\right) - \left(y_{t-1} - y_{t-1}^n\right)\right)^2 . \end{aligned} \tag{12}$$

Assume now that the economy is in steady state at $t = 0$. If, say, a positive technology shock arrives in period 1, then it is evident from (12) that the central bank faces no trade-off in policy. It expands output to match y_t^n and this results in no inflationary pressures. Although nominal income growth rises, it is irrelevant for the central bank as the target value has increased accordingly. Whatever the process for y_t^n, future periods will entail no policy trade-offs either. Only in the case where the economy is off steady state, inefficiency remains. With cost-push shocks this, of course, happens with probability one in every period, but the inefficiency is of little quantitative importance.

For example, for the baseline parameter configuration, the optimal regime of the form (12), yields a societal loss ($\times 100$) of 4.5998. In comparison, as described in Footnote 22, the societal loss under optimal constant NIGT when $\sigma_y = 0$ is 4.5995. Clearly then, if state-contingent NIGT as described here is feasible, then its relative advantage over IT is strengthened since the inefficiencies due to technology shocks become trivial.

5.3. Inertial behavior through other targeting regimes?

Since the precommitment solution of the model features inertial interest rate behavior towards shocks that create a policy trade-off, an obvious candidate for a targeting variable is the *change* in the interest rate. This amounts to letting a term $(i_t - i_{t-1})^2$ — an interest rate smoothing objective — enter the loss function. Straightforwardly, this induces inertial behavior in a discretionary equilibrium. However, it will not provide any gains if such a nominal target appears along with the output gap alone (it is easy to see that the central bank would simply remain passive towards a cost-push shock). So, adding this objective necessitates a combination regime where the contemporaneous loss function takes a form of, for example, $\lambda x_t^2 + \pi_t^2 + \eta (i_t - i_{t-1})^2$ where η is some weight.[23] Whether a regime of this sort outperforms NIGT is a question awaiting future research. I offer, however, a few conjectures speaking against interest rate smoothing compared to NIGT.

First, instructing the central bank to pay attention to its past behavior prevents it from neutralizing the economy from demand shocks. Hence, interest rate smoothing will, in comparison with NIGT (as well as IT) induce a societal loss arising from demand shocks.[24] This loss will furthermore be increasing in η and thus hamper the necessary degree of inertia when the effects of cost-push shocks become more persistent (the optimal value of η will most likely be decreasing in σ_g). Secondly, endogenous persistence in demand is another source of inferiority of interest rate smoothing relative to NIGT. The reason is that any past demand will be allowed to affect current demand and output gap when the interest rate is not free to neutralize it. The result will be prolonged deviations of the output gap and inflation from steady state not present under NIGT (or IT).

Another candidate regime would be to target the price *level* (in addition to the output gap). As shown by Clarida et al. (1999a, Appendix), the precommitment solution in the case of no endogenous persistence ($\theta = \phi = 0$) is characterized by a price level path involving a reversion to the initial price level. This is intuitive: following an inflationary shock, a commitment to hit the initial price level in the long run, inevitable involves creating deflation in future periods which is exactly what dampens current inflation when (3) applies. Including a term $(p_t - p_0)^2$ in the loss function could thus be a commitment to prolonged contractions.[25] One problem with such a strategy is, of course, if the socially optimal inflation rate is non-zero. Also, in the case of endogenous inflation persistence, it is suboptimal having the price level return to its starting value. For example, in the baseline scenario considered here, prices under precommitment converge to a level about one percent higher than the initial value after the economy has been hit by a temporary cost-push shock of 1.5 percent.

Finally, one could also imagine that *real* output growth targeting of some form could

[23] After completing the first draft of this paper, I became aware of the revised version of Woodford (1998), Woodford (1999). In this version, discretionary behavior is considered when the central bank, in addition to the social loss function, is also assigned an interest rate smoothing objective. It is shown, in line with the above conjectures, that this indeed reduces the loss under discretion as it induces beneficial inertial interest rate behavior.

[24] It will, of course, also respond inefficiently towards technology shocks. Whether this inefficiency is of smaller or larger magnitude than that accruing from NIGT is an open question. (If NIGT can be state-contingent as described in Section 5.2, it is most likely less inefficient in this dimension than a regime encouraging interest rate smoothing.)

[25] This conjecture has recently been formally validated by Vestin (1999).

generate the needed inertial policy behavior. Indeed, the argument behind the benefits of NIGT is that it induces a continuation of contractive policy because when output was low in the past, nominal income growth is increasing. Surely, real income grows as well. Also, the term involving nominal income growth in the loss function $\psi\left(\pi_t + y_t - y_{t-1}\right)^2$ can be expanded as $\psi\left[\pi_t^2 + \left(y_t - y_{t-1}\right)^2 + 2\pi_t\left(y_t - y_{t-1}\right)\right]$ which indeed involves inflation and real output growth. Whether the cross-term present under NIGT is of value or not is an open question. Note, however, that a real output growth targeting regime would have to be a "combination regime" where inflation, the output gap and real output growth are targeted.

5.4. Optimal regimes in presence of transmission lags of policy

An obvious shortcoming of the adopted model framework is the absence of realistic lags in the transmission from policy actions to macroeconomic aggregates. It is probably fair to say that conventional wisdom is that changes in the interest rate affect demand with some lag, and that demand (or, more precisely, the output gap) then affects inflation with further lag(s). In such a setting, the central bank cannot perfectly insulate the economy from demand and technology shocks (see, e.g., Svensson, 1997b). A positive demand shock will, e.g., lead to an immediate increase in the output gap that will translate into higher future inflation. In responding towards this higher expected inflation, the central bank contracts, trading off the adverse consequences for the expected future output gap and the benefits of reducing expected future inflation.

It is conceivable that under such circumstances, an inertial monetary policy response will be beneficial if inflation (at the time it is affected by the policy response) depends upon expectations about future inflation (as is the case in, e.g., Svensson, 1999b). Again, the reason being that it helps reducing inflation at a smaller cost in terms of the output gap. Hence, NIGT could again prove superior to IT in models featuring lags in the policy transmission. An open issue, however, is the quantitative importance of choosing the appropriate regime. One may speculate that a credibility problem of monetary policy becomes less severe the longer it takes policy to take effect (see, e.g., Goodhart and Huang, 1998, on this argument in a different type of model). Hence, the welfare differences between precommitment and discretionary regimes may be smaller. On the other hand, with the very little degree of discounting adopted here, one would imagine that the policy lags should be quite long in order for credibility problems to become trivial.

6. Concluding remarks

Optimal monetary policy in a world characterized by the "New Neoclassical Synthesis" features inertial behavior. This has recently been emphasized by, for example, Clarida et al. (1999a), Rotemberg and Woodford (1997) and Woodford (1998). The reason is that such behavior improves the inflation-output gap trade-off by influencing expectations about future inflation in a manner that stabilizes current inflation. Since monetary policy under IT is not inertial, but policy under NIGT is, this paper has pointed towards the potential superiority of the latter as a monetary policy regime. Conditions increasing the likelihood of this superiority are the following.

First, the main sources of economic fluctuations should not be shocks that pose no societal trade-offs in policymaking. Obviously, this would render targeting regimes that improve the inflation-output gap trade-off superfluous. Therefore, shocks creating a policy problem — in this paper cost-push shocks — must play a role. In contrast, technology shocks (which poses no societal trade-off) should not be predominant, as these are inefficiently handled under (constant) NIGT. The inefficiency seemed, however, only to be of quantitative importance for unrealistically high volatility of technology shocks.

Secondly, more persistence of inflation-generating shocks increases the need of committing to future contractions thus strengthening the case for NIGT. This also applies when the endogenous propagation of inflation shocks exhibits more persistence (although this should not be to an extent making expected future inflation of insignificant importance in price-setting behavior). Thirdly, the elasticity of inflation with respect to the output gap should not be too high. If it was, the inflation-output gap trade-off is rather favorable and an improvement through NIGT would be unwarranted. Finally, society should not be predominantly concerned with output fluctuations, because a regime that is superior in terms of stabilizing inflation would then not be appreciated. In consequence, IT should be implemented when society cares little about inflation.

The results presented in this paper show that NIGT exhibits virtues within a model framework that usually serves as a vehicle for endorsing IT. Obviously, it therefore deserves more serious attention in discussions on real-life policy design than has recently been the case.[26]

[26] For example, in the debate concerning the monetary policy strategy of the European Central Bank, most emphasis has been on inflation or money supply targeting (see, e.g., Svensson, 1999c). Nominal income growth targeting is usually not mentioned at all.

Appendix

A. Characterization of the precommitment solution

Details on the derivation of the precommitment solution in dynamic rational expectations models are provided in, e.g., Backus and Driffill (1986) and Currie and Levine (1993). The exposition here follows very closely that of Svensson (1994, Appendix 1), see also, e.g., Flodén (1996) and Söderlind (1999). It is, however, simplified by the fact the policy instrument i_t does not enter the contemporaneous loss. Now, if one temporarily (and counterfactually) treats all variables of the model as pre-determined, the decision problem is a conventional dynamic programming one (cf. Backus and Driffill, 1986). I.e.,

$$J\left(\mathbf{Z}_t\right) = \mathbf{Z}_t'\mathbf{V}_t\mathbf{Z}_t + W_t \equiv \min_{i_t}\left\{\mathbf{Z}_t'\mathbf{Q}\mathbf{Z}_t + \beta \mathrm{E}_t\left(\mathbf{Z}_{t+1}'\mathbf{V}_{t+1}\mathbf{Z}_{t+1} + W_{t+1}\right)\right\}, \qquad (A.1)$$

where $\mathbf{V}_t$ is the (unknown) value function matrix and W_t is a scalar. The relevant first-order condition is

$$i_t = -\mathbf{F}_t\mathbf{Z}_t, \qquad (A.2)$$

where $\mathbf{F}_t \equiv \left(\mathbf{B}'\mathbf{V}_{t+1}\mathbf{B}\right)^{-1}\mathbf{B}'\mathbf{V}_{t+1}\mathbf{A}$. Inserting (A.2) back into (A.1), and using (9), one recovers the following matrix Riccati difference equations:

$$\mathbf{V}_t = \mathbf{Q} + \beta\left(\mathbf{A} - \mathbf{B}\mathbf{F}_t\right)'\mathbf{V}_{t+1}\left(\mathbf{A} - \mathbf{B}\mathbf{F}_t\right), \qquad (A.3)$$

$$W_t = \beta W_{t+1} + \beta \mathrm{trace}\left(\mathbf{V}_{t+1}\mathbf{\Sigma}_{ZZ}\right), \qquad (A.4)$$

where $\mathbf{\Sigma}_{ZZ}$ is the covariance matrix of the shocks in $\mathbf{Z}$. Starting with some guess for $\mathbf{V}_{t+1}$ (a 8×8 identity matrix was used), iterating "backwards in time" on (A.3) leads to the stationary solution for $\mathbf{V}$. The stationary solution for W then follows by (A.4) as $W = (\beta/[1-\beta])\mathrm{trace}(\mathbf{V}_{t+1}\mathbf{\Sigma}_{ZZ})$. In all numerical simulations, convergence was achieved fast ($2 - 3,000$ iterations) and without problems.

All variables in $\mathbf{Z}_t$, however, are not predetermined. Therefore, Backus and Driffill (1986) demonstrated how to handle the presence of forward-looking variables. First, partition $\mathbf{V}$ according to the decomposition of $\mathbf{Z}$ into predetermined and forward-looking variables:

$$\mathbf{V} \equiv \begin{bmatrix} \mathbf{V}_{11} & \mathbf{V}_{12} \\ \mathbf{V}_{21} & \mathbf{V}_{22} \end{bmatrix},$$

where $\mathbf{V}_{11}$ is 6×6, $\mathbf{V}_{22}$ is 2×2, $\mathbf{V}_{21}$ is 2×6 and $\mathbf{V}_{12}$ is 6×2. Then, define the matrix $\mathbf{V}^* \equiv \mathbf{V}_{11} - \mathbf{V}_{12}\mathbf{V}_{22}^{-1}\mathbf{V}_{21}$. The optimal loss, conditional on period 1 information, can then be found as

$$J(\mathbf{X}_1) = \mathbf{X}_1'\mathbf{V}^*\mathbf{X}_1 + \frac{\beta}{1-\beta}\text{trace}\left[\mathbf{V}^*\boldsymbol{\Sigma}_{XX}\right], \tag{A.5}$$

where $\boldsymbol{\Sigma}_{XX}$ is the 6×6 covariance matrix of shocks to $\mathbf{X}$. I.e., $\boldsymbol{\Sigma}_{XX} \equiv \mathrm{E}_t\left[\boldsymbol{\zeta}_{t+1}\boldsymbol{\zeta}_{t+1}'\right]$. The value of L under precommitment, L^P, then follows as

$$\begin{aligned} L^P &= \mathrm{E}_0\left[J(\mathbf{X}_1)\right] = \mathrm{E}_0\left[\mathbf{X}_1'\mathbf{V}^*\mathbf{X}_1\right] + \frac{\beta}{1-\beta}\text{trace}\left[\mathbf{V}^*\boldsymbol{\Sigma}_{XX}\right] \\ &= \mathrm{E}_0\left[\mathbf{X}_1'\right]\mathbf{V}^*\mathrm{E}_0\left[\mathbf{X}_1\right] + \frac{1}{1-\beta}\text{trace}\left[\mathbf{V}^*\boldsymbol{\Sigma}_{XX}\right]. \end{aligned} \tag{A.6}$$

To express the equilibrium dynamics of the solution, the following auxiliary matrices are needed:

$$\begin{aligned} \mathbf{T} &\equiv \begin{bmatrix} \mathbf{I}_6 & \mathbf{0}_{6\times 2} \\ \mathbf{V}_{21} & \mathbf{V}_{22} \end{bmatrix}, \quad \widetilde{\mathbf{M}} \equiv \mathbf{T}\left(\mathbf{A}-\mathbf{BF}\right)\mathbf{T}^{-1} = \begin{bmatrix} \widetilde{\mathbf{M}}_{11} & \widetilde{\mathbf{M}}_{12} \\ \widetilde{\mathbf{M}}_{21} & \widetilde{\mathbf{M}}_{22} \end{bmatrix}, \\ \mathbf{L} &\equiv \left[\mathbf{L}_1 \quad \mathbf{L}_2\right] = \left[-\mathbf{V}_{22}^{-1}\mathbf{V}_{21} \quad \mathbf{V}_{22}^{-1}\right], \end{aligned}$$

where $\mathbf{I}_6$ is the 6×6 identity matrix and where $\widetilde{\mathbf{M}}$ is partitioned according to the decomposition of $\mathbf{Z}$. The solution is then obtained in terms of the predetermined variables $\mathbf{X}_t$ and the shadow prices, $\mathbf{P}_t$, of the forward-looking variables $\boldsymbol{\chi}_t$. The shadow prices fulfill by definition $\mathbf{P}_t = \mathbf{V}_{21}\mathbf{X}_t + \mathbf{V}_{22}\boldsymbol{\chi}_t$, so the solution can be expressed as

$$\begin{bmatrix} \mathbf{X}_{t+1} \\ \mathbf{P}_{t+1} \end{bmatrix} = \widetilde{\mathbf{M}} \begin{bmatrix} \mathbf{X}_t \\ \mathbf{P}_t \end{bmatrix} + \begin{bmatrix} \boldsymbol{\zeta}_{t+1} \\ \mathbf{0}_{2\times 1} \end{bmatrix}, \tag{A.7}$$

where $\mathbf{X}_1$ is given, and $\mathbf{P}_1 = 0$ (since under precommitment the jump-variables can be set in whatever fashion desired; hence, their shadow price is zero). Moreover, the interest rate is given by

$$i_t = -\mathbf{F}\mathbf{T}^{-1}\begin{bmatrix} \mathbf{X}_t \\ \mathbf{P}_t \end{bmatrix}. \tag{A.8}$$

Finally, the unconditional covariance matrix of the state variables, $\overline{\boldsymbol{\Sigma}}_{ZZ}$, is found as the solution to

$$\overline{\boldsymbol{\Sigma}}_{ZZ} = \mathbf{M}\overline{\boldsymbol{\Sigma}}_{ZZ}\mathbf{M}' + \boldsymbol{\Sigma}_{ZZ}, \tag{A.9}$$

where

$$\mathbf{M} = \begin{bmatrix} \widetilde{\mathbf{M}}_{11} + \widetilde{\mathbf{M}}_{12}\mathbf{V}_{21} & \widetilde{\mathbf{M}}_{12}\mathbf{V}_{22} \\ \mathbf{L}_1\left(\widetilde{\mathbf{M}}_{11} + \widetilde{\mathbf{M}}_{12}\mathbf{V}_{21}\right) + \mathbf{L}_2\left(\widetilde{\mathbf{M}}_{21} + \widetilde{\mathbf{M}}_{22}\mathbf{V}_{21}\right) & \left(\mathbf{L}_1\widetilde{\mathbf{M}}_{12} + \mathbf{L}_2\widetilde{\mathbf{M}}_{22}\right)\mathbf{V}_{22} \end{bmatrix},$$

$$\boldsymbol{\Sigma}_{ZZ} = \begin{bmatrix} \boldsymbol{\Sigma}_{XX} & \boldsymbol{\Sigma}_{XX}\mathbf{L}_1' \\ \mathbf{L}_1\boldsymbol{\Sigma}_{XX} & \mathbf{L}_1\boldsymbol{\Sigma}_{XX}\mathbf{L}_1' \end{bmatrix}.$$

B. Characterization of the solution under discretion

Details on solving for discretionary policy in dynamic rational expectations models are found in Oudiz and Sachs (1985), Backus and Driffill (1986) and Currie and Levine (1993), *inter alia*. The following exposition builds again closely on Svensson (1994, Appendix 1); see also, e.g., Flodén (1996) or Söderlind (1999). Since, in each period, the central bank re-optimizes, it only takes current states into account. In consequence, any period's forward-looking variables depend upon current states only (any promises the central bank may make about future policy are not credible). Hence, in a discretionary equilibrium it must the case that $\widehat{\boldsymbol{\chi}}_t = \widehat{\mathbf{C}}\widehat{\mathbf{X}}_t$, where $\widehat{\mathbf{C}}$ is some 2×5 matrix. The discretionary solution can then be shown to be characterized by the following equations:

$$J\left(\widehat{\mathbf{X}}_1\right) = \widehat{\mathbf{X}}'\widehat{\mathbf{V}}^*\widehat{\mathbf{X}}_1 + \frac{\beta}{1-\beta}\text{trace}\left(\widehat{\mathbf{V}}^*\boldsymbol{\Sigma}_{\widehat{X}\widehat{X}}\right), \tag{B.1}$$

$$\widehat{\mathbf{X}}_t = \left(\widehat{\mathbf{A}}^* - \widehat{\mathbf{B}}^*\widehat{\mathbf{F}}^*\right)\widehat{\mathbf{X}}_{t-1} + \widehat{\boldsymbol{\zeta}}_t, \tag{B.2}$$

$$i_t = -\widehat{\mathbf{F}}^*\widehat{\mathbf{X}}_t, \tag{B.3}$$

where $\widehat{\mathbf{C}}$, $\widehat{\mathbf{V}}^*$, $\widehat{\mathbf{A}}^*$, $\widehat{\mathbf{B}}^*$, and $\widehat{\mathbf{F}}^*$ are unknown matrices, and $\boldsymbol{\Sigma}_{\widehat{X}\widehat{X}}$ is the 5×5 covariance matrix of shocks to $\widehat{\mathbf{X}}$, i.e., $\boldsymbol{\Sigma}_{\widehat{X}\widehat{X}} \equiv \mathrm{E}_t\left[\widehat{\boldsymbol{\zeta}}_{t+1}\widehat{\boldsymbol{\zeta}}_{t+1}'\right]$.

To determine the unknown matrices of (B.1)-(B.3), start by decomposing matrices $\widehat{\mathbf{A}}$, $\widehat{\mathbf{Q}}$, and $\widehat{\mathbf{B}}$ according to the decomposition of $\widehat{\mathbf{Z}}_t$:

$$\widehat{\mathbf{A}} = \begin{bmatrix} \widehat{\mathbf{A}}_{11} & \widehat{\mathbf{A}}_{12} \\ \widehat{\mathbf{A}}_{21} & \widehat{\mathbf{A}}_{22} \end{bmatrix}, \quad \widehat{\mathbf{Q}} = \begin{bmatrix} \widehat{\mathbf{Q}}_{11} & \widehat{\mathbf{Q}}_{12} \\ \widehat{\mathbf{Q}}_{21} & \widehat{\mathbf{Q}}_{22} \end{bmatrix}, \quad \widehat{\mathbf{B}} = \begin{bmatrix} \widehat{\mathbf{B}}_1 \\ \widehat{\mathbf{B}}_2 \end{bmatrix}.$$

Then proceed according to the following algorithm:

1. Given some $\widehat{\mathbf{C}}_{t+1}$, matrices $\widehat{\mathbf{D}}_t$ and $\widehat{\mathbf{G}}_t$ are defined as

$$\widehat{\mathbf{D}}_t \equiv \left(\widehat{\mathbf{A}}_{22} - \widehat{\mathbf{C}}_{t+1}\widehat{\mathbf{A}}_{12}\right)^{-1}\left(\widehat{\mathbf{C}}_{t+1}\widehat{\mathbf{A}}_{11} - \widehat{\mathbf{A}}_{21}\right),$$

$$\widehat{\mathbf{G}}_t \equiv \left(\widehat{\mathbf{A}}_{22} - \widehat{\mathbf{C}}_{t+1}\widehat{\mathbf{A}}_{12}\right)^{-1}\left(\widehat{\mathbf{C}}_{t+1}\widehat{\mathbf{B}}_1 - \widehat{\mathbf{B}}_2\right),$$

   and by use of these, $\widehat{\mathbf{A}}_t^*$ and $\widehat{\mathbf{B}}_t^*$ are defined as

$$\widehat{\mathbf{A}}_t^* \equiv \widehat{\mathbf{A}}_{11} + \widehat{\mathbf{A}}_{12}\widehat{\mathbf{D}}_t,$$

$$\widehat{\mathbf{B}}_t^* \equiv \widehat{\mathbf{A}}_{12}\widehat{\mathbf{G}}_t + \widehat{\mathbf{B}}_1.$$

2. Then, matrices $\widehat{\mathbf{Q}}_t^*$, $\widehat{\mathbf{U}}_t^*$ and $\widehat{\mathbf{R}}_t^*$ are formed:

$$\begin{aligned}
\widehat{\mathbf{Q}}_t^* &= \widehat{\mathbf{Q}}_{11} + \widehat{\mathbf{Q}}_{12}\widehat{\mathbf{D}}_t + \widehat{\mathbf{D}}_t'\widehat{\mathbf{Q}}_{21} + \widehat{\mathbf{D}}_t'\widehat{\mathbf{Q}}_{22}\widehat{\mathbf{D}}_t, \\
\widehat{\mathbf{U}}_t^* &= \widehat{\mathbf{Q}}_{12}\widehat{\mathbf{G}}_t + \widehat{\mathbf{D}}_t'\widehat{\mathbf{Q}}_{22}\widehat{\mathbf{G}}_t, \\
\widehat{\mathbf{R}}^* &= \widehat{\mathbf{G}}_t'\widehat{\mathbf{Q}}_{22}\widehat{\mathbf{G}}_t.
\end{aligned}$$

3. Given $\widehat{\mathbf{V}}_{t+1}^*$ the matrices $\widehat{\mathbf{F}}_t^*$ and $\widehat{\mathbf{V}}_t^*$ follow as

$$\begin{aligned}
\widehat{\mathbf{F}}_t^* &= \left(\beta\widehat{\mathbf{B}}_t^{*\prime}\widehat{\mathbf{V}}_{t+1}^*\widehat{\mathbf{B}}_t^* + \widehat{\mathbf{R}}_t^*\right)^{-1}\left(\beta\widehat{\mathbf{B}}_t^{*\prime}\widehat{\mathbf{V}}_{t+1}^*\widehat{\mathbf{A}}_t^* + \widehat{\mathbf{U}}_t^{*\prime}\right), \\
\widehat{\mathbf{V}}_t^* &= \beta\left(\widehat{\mathbf{A}}_t^* - \widehat{\mathbf{B}}_t^*\widehat{\mathbf{F}}_t^*\right)'\widehat{\mathbf{V}}_{t+1}^*\left(\widehat{\mathbf{A}}_t^* - \widehat{\mathbf{B}}_t^*\widehat{\mathbf{F}}_t^*\right) + \widehat{\mathbf{Q}}_t^* - \widehat{\mathbf{U}}_t^*\widehat{\mathbf{F}}_t^* - \widehat{\mathbf{F}}_t^{*\prime}\widehat{\mathbf{U}}_t^{*\prime} + \widehat{\mathbf{F}}_t^{*\prime}\widehat{\mathbf{R}}_t^*\widehat{\mathbf{F}}_t^*.
\end{aligned}$$

4. $\widehat{\mathbf{C}}_t$ is then found as

$$\widehat{\mathbf{C}}_t = \widehat{\mathbf{D}}_t - \widehat{\mathbf{G}}_t\widehat{\mathbf{F}}_t^*.$$

Starting with some initial guess of $\widehat{\mathbf{C}}$ and $\widehat{\mathbf{V}}^*$ (identity matrices worked out fine), perform steps $1-4$ successively "back in time" until the system has converged to a stationary solution. As was the case with the solution under precommitment, convergence was in all simulations achieved rather fast (around $3,000$ iterations).

Note now by (B.2), and the fact that $\widehat{\chi}_t = \widehat{\mathbf{C}}\widehat{\mathbf{X}}_t$, that equilibrium dynamics can be described in terms of $\widehat{\mathbf{Z}}_t$ as

$$\widehat{\mathbf{Z}}_t = \begin{bmatrix} \left(\widehat{\mathbf{A}}^* - \widehat{\mathbf{B}}^*\widehat{\mathbf{F}}^*\right) & \mathbf{0}_{5\times 2} \\ \widehat{\mathbf{C}}\left(\widehat{\mathbf{A}}^* - \widehat{\mathbf{B}}^*\widehat{\mathbf{F}}^*\right) & \mathbf{0}_{2\times 2} \end{bmatrix}\widehat{\mathbf{Z}}_{t-1} + \begin{bmatrix} \mathbf{I}_5 \\ \widehat{\mathbf{C}} \end{bmatrix}\widehat{\zeta}_t. \tag{B.4}$$

The unconditional covariance matrix of the state variables, $\overline{\mathbf{\Sigma}}_{\widehat{Z}\widehat{Z}}$, is then found as the solution to

$$\overline{\mathbf{\Sigma}}_{\widehat{Z}\widehat{Z}} = \begin{bmatrix} \left(\widehat{\mathbf{A}}^* - \widehat{\mathbf{B}}^*\widehat{\mathbf{F}}^*\right) & \mathbf{0}_{5\times 2} \\ \widehat{\mathbf{C}}\left(\widehat{\mathbf{A}}^* - \widehat{\mathbf{B}}^*\widehat{\mathbf{F}}^*\right) & \mathbf{0}_{2\times 2} \end{bmatrix}\overline{\mathbf{\Sigma}}_{\widehat{Z}\widehat{Z}}\begin{bmatrix} \left(\widehat{\mathbf{A}}^* - \widehat{\mathbf{B}}^*\widehat{\mathbf{F}}^*\right) & \mathbf{0}_{5\times 2} \\ \widehat{\mathbf{C}}\left(\widehat{\mathbf{A}}^* - \widehat{\mathbf{B}}^*\widehat{\mathbf{F}}^*\right) & \mathbf{0}_{2\times 2} \end{bmatrix}' + \mathbf{\Sigma}_{\widehat{Z}\widehat{Z}}, \tag{B.5}$$

where

$$\mathbf{\Sigma}_{\widehat{Z}\widehat{Z}} \equiv \begin{bmatrix} \mathbf{\Sigma}_{\widehat{X}\widehat{X}} & \mathbf{\Sigma}_{\widehat{X}\widehat{X}}\widehat{\mathbf{C}}' \\ \widehat{\mathbf{C}}\mathbf{\Sigma}_{\widehat{X}\widehat{X}} & \widehat{\mathbf{C}}\mathbf{\Sigma}_{\widehat{X}\widehat{X}}\widehat{\mathbf{C}}' \end{bmatrix}. \tag{B.6}$$

C. Society's loss under discretionary targeting regimes

As a first step in determining society's welfare loss from discretionary policy under a targeting regime, one finds society's contemporaneous loss in terms of $\widehat{\mathbf{Z}}_t$: $\lambda\left(y_t - y_t^n\right)^2 + \pi_t^2 = \widehat{\mathbf{Z}}_t'\widetilde{\mathbf{Q}}\widehat{\mathbf{Z}}_t$ where

$$\widetilde{\mathbf{Q}} \equiv \begin{bmatrix} 0 & 0 & \mathbf{0}_{1\times3} & 0 & 0 \\ 0 & \lambda & \mathbf{0}_{1\times3} & -\lambda & 0 \\ \mathbf{0}_{3\times1} & \mathbf{0}_{3\times1} & \mathbf{0}_{3\times3} & \mathbf{0}_{3\times1} & \mathbf{0}_{3\times1} \\ 0 & -\lambda & \mathbf{0}_{1\times3} & \lambda & 0 \\ 0 & 0 & \mathbf{0}_{1\times3} & 0 & 1 \end{bmatrix}.$$

Society's loss, conditional on period t information, is by definition given by

$$\widehat{\mathbf{Z}}_t'\widetilde{\mathbf{V}}_t\widehat{\mathbf{Z}}_t + \widetilde{W}_t = \widehat{\mathbf{Z}}_t'\widetilde{\mathbf{Q}}\widehat{\mathbf{Z}}_t + \beta \mathrm{E}_t\left[\widehat{\mathbf{Z}}_{t+1}'\widetilde{\mathbf{V}}_{t+1}\widehat{\mathbf{Z}}_{t+1} + \widetilde{W}_{t+1}\right],$$

where $\widetilde{\mathbf{V}}_t$ are the unknown value function matrix and $\widetilde{W}_t$ is a scalar. Since equilibrium dynamics under targeting is given by (B.4), it follows that the following difference equations must be satisfied:

$$\begin{aligned} \widetilde{\mathbf{V}}_t &= \widetilde{\mathbf{Q}} + \beta \begin{bmatrix} \left(\widehat{\mathbf{A}}^* - \widehat{\mathbf{B}}^*\widehat{\mathbf{F}}^*\right) & \mathbf{0}_{5\times2} \\ \widehat{\mathbf{C}}\left(\widehat{\mathbf{A}}^* - \widehat{\mathbf{B}}^*\widehat{\mathbf{F}}^*\right) & \mathbf{0}_{2\times2} \end{bmatrix}' \widetilde{\mathbf{V}}_{t+1} \begin{bmatrix} \left(\widehat{\mathbf{A}}^* - \widehat{\mathbf{B}}^*\widehat{\mathbf{F}}^*\right) & \mathbf{0}_{5\times2} \\ \widehat{\mathbf{C}}\left(\widehat{\mathbf{A}}^* - \widehat{\mathbf{B}}^*\widehat{\mathbf{F}}^*\right) & \mathbf{0}_{2\times2} \end{bmatrix} \\ \widetilde{W}_t &= \beta\widetilde{W}_{t+1} + \beta \mathrm{trace}\left(\widetilde{\mathbf{V}}_{t+1}\mathbf{\Sigma}_{\widehat{Z}\widehat{Z}}\right). \end{aligned}$$

It is straightforward to iterate on the first of these (starting with some initial guess for $\widetilde{\mathbf{V}}_{t+1}$; again an identity matrix works well), and when the stationary solution $\widetilde{\mathbf{V}}$ is found, one finds $\widetilde{W} = [\beta/(1-\beta)]\mathrm{trace}\left(\widetilde{\mathbf{V}}\mathbf{\Sigma}_{\widehat{Z}\widehat{Z}}\right)$. As the aim is to evaluate society's loss conditional on period 0 information, the loss under discretion, L^D, is ultimately found as

$$\begin{aligned} L^D &= \mathrm{E}_0\left[\widehat{\mathbf{Z}}_1'\widetilde{\mathbf{V}}\widehat{\mathbf{Z}}_1\right] + \frac{\beta}{1-\beta}\mathrm{trace}\left(\widetilde{\mathbf{V}}\mathbf{\Sigma}_{\widehat{Z}\widehat{Z}}\right) \\ &= \mathrm{E}_0\left[\widehat{\mathbf{Z}}_1'\right]\widetilde{\mathbf{V}}\mathrm{E}_0\left[\widehat{\mathbf{Z}}_1\right] + \frac{1}{1-\beta}\mathrm{trace}\left(\widetilde{\mathbf{V}}\mathbf{\Sigma}_{\widehat{Z}\widehat{Z}}\right). \end{aligned} \tag{C.1}$$

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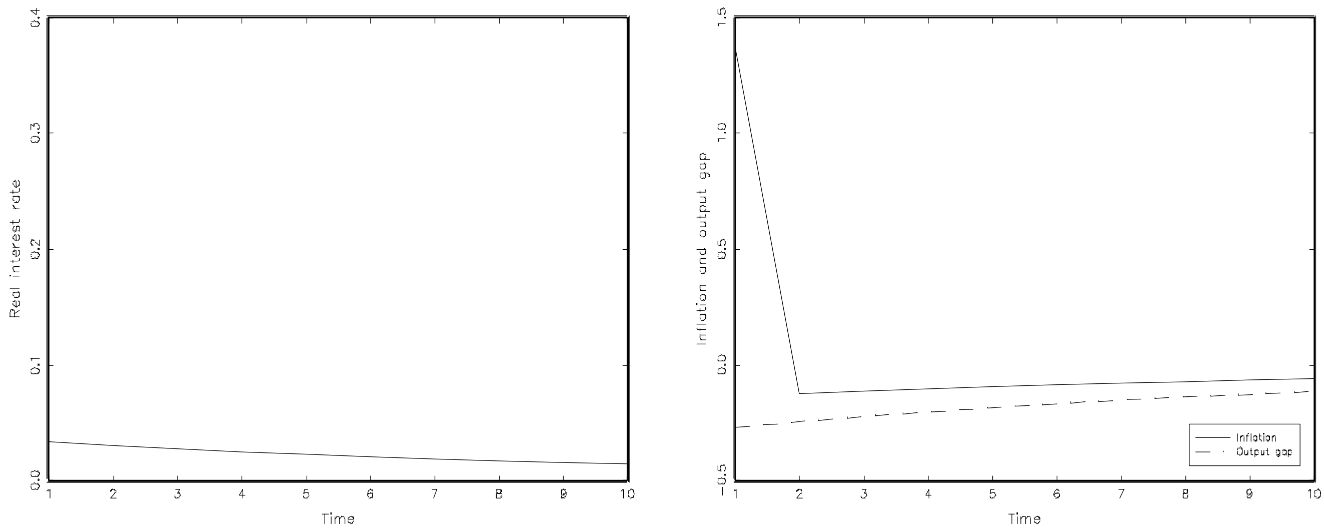

Figure 1: Real interest rate, inflation and output gap following a temporary cost-push shock. Precommitment and no endogenous persistence.

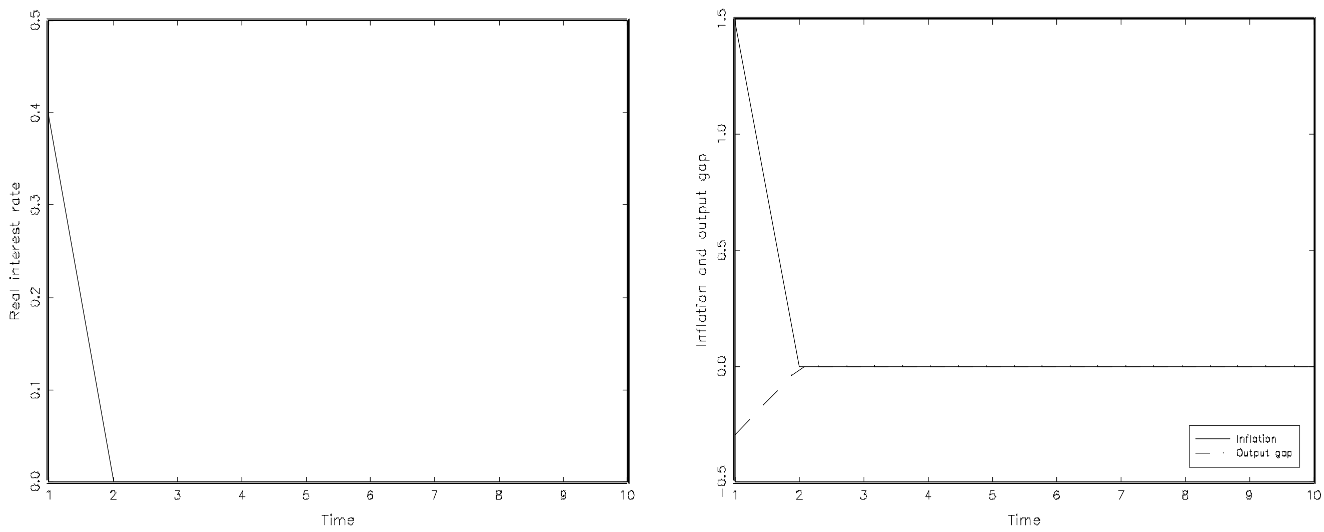

Figure 2: Real interest rate, inflation and output gap following a temporary cost-push shock. Pure discretion and no endogenous persistence (corresponds to optimal IT).

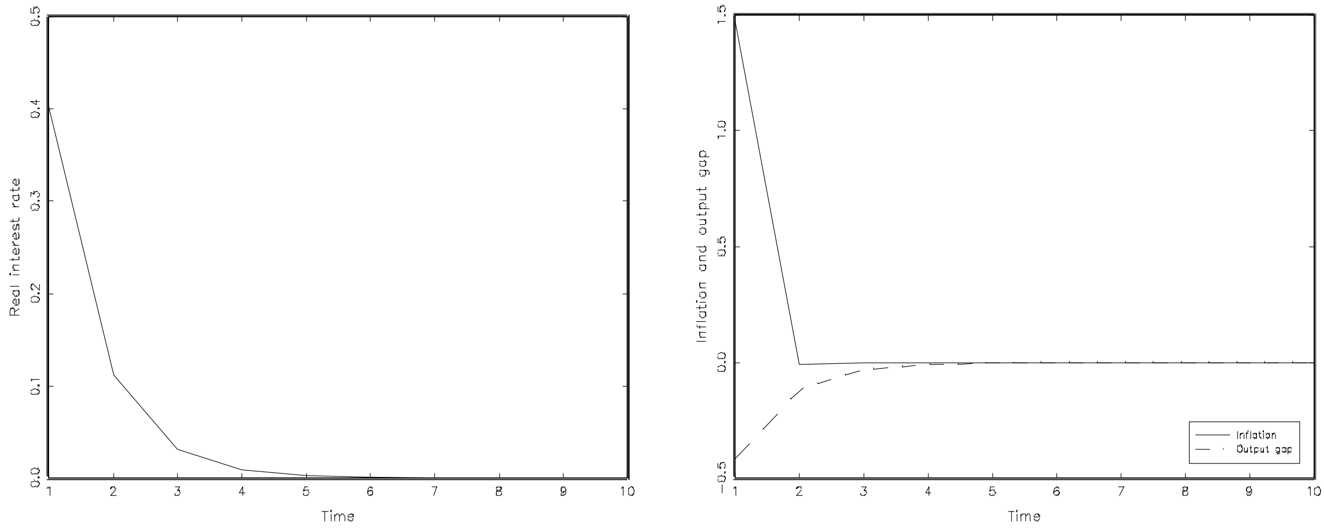

Figure 3: Real interest rate, inflation and output gap following a temporary cost-push shock. Optimal NIGT and no endogenous persistence.

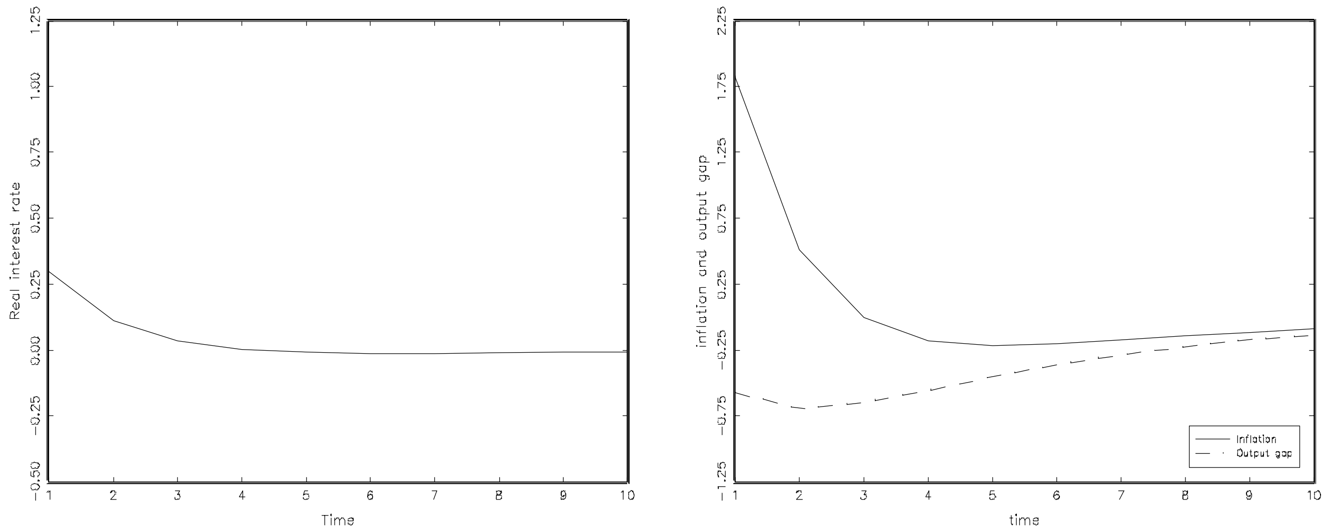

Figure 4: Real interest rate, inflation and output gap following a temporary cost-push shock. Precommitment and baseline parameter values.

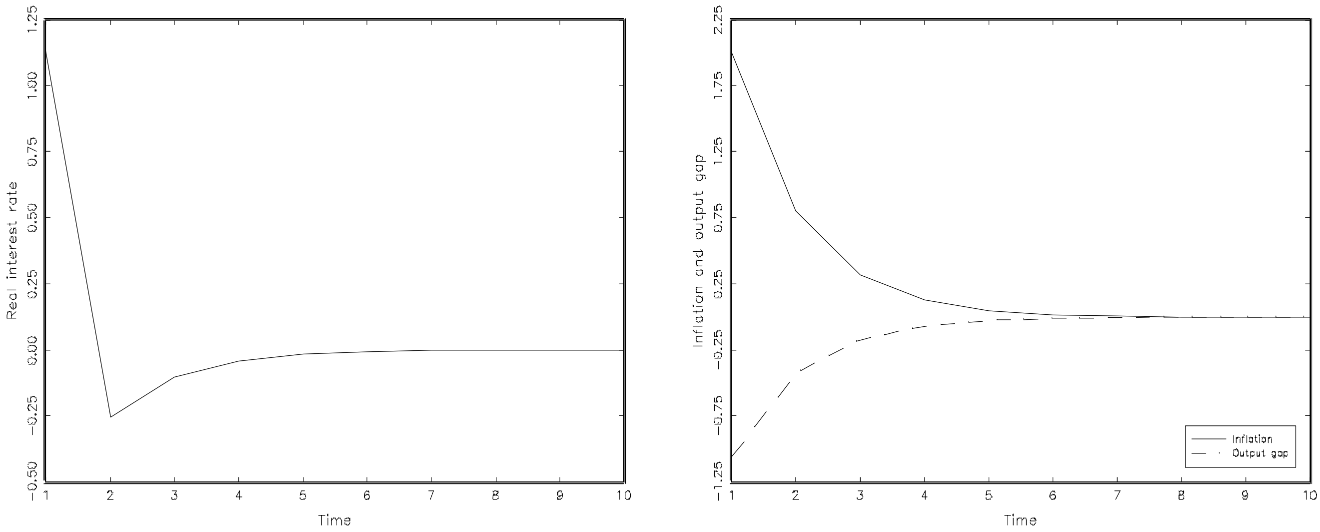

Figure 5: Real interest rate, inflation and output gap following a temporary cost-push shock. Optimal IT and baseline parameter values.

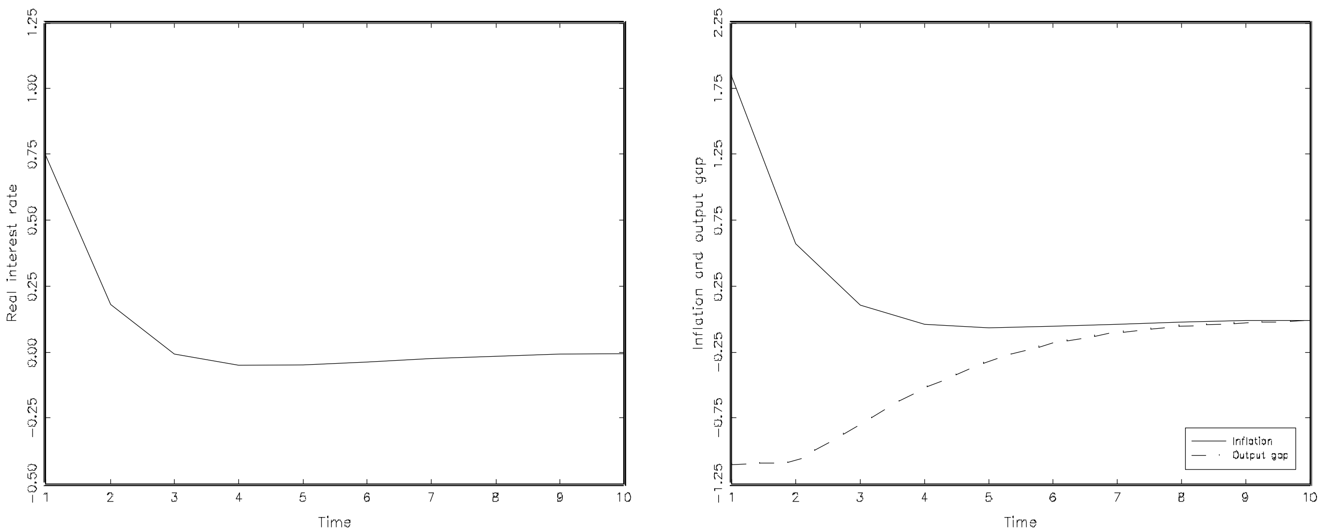

Figure 6: Real interest rate, inflation and output gap following a temporary cost-push shock. Optimal NIGT and baseline parameter values.

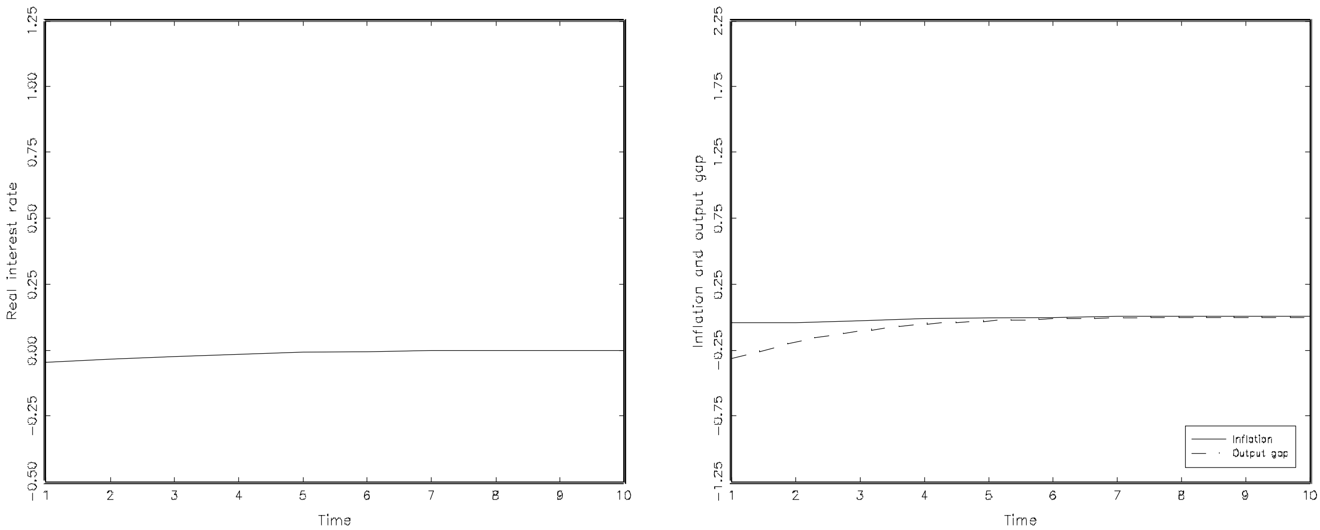

Figure 7: Real interest rate, inflation and output gap following a technology shock. Optimal NIGT and baseline parameter values.