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OPTIMAL MONETARY POLICY UNDER LOW TREND INFLATION

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Abstract

In the monetary policy literature it is commonly assumed that trend inflation is zero, despite overwhelming evidence that zero inflation is neither empirically relevant nor a practical objective for central bank policy. We therefore extend the standard New Keynesian model to allow for positive trend inflation, showing that even low trend inflation has strong effects on optimal monetary policy and the dynamics of inflation, output, and interest rates. Under discretion, the efficient policy deteriorates and there is no guarantee of determinacy. Even with commitment, targeting non-zero trend inflation leads to substantial welfare losses. Our results serve as a warning against indiscriminate use of models assuming zero trend inflation.

JEL Classification: E31, E52.
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1 Introduction

In May 2003 the ECB explicitly announced its view that price stability corresponds to an inflation rate below but close to 2% over the medium term. Unfortunately, most theoretical models in the recent literature say little about how a positive inflation target such as this is likely to affect the optimal short-run stabilization policy of the ECB. Indeed, with few notable exceptions (e.g., Khan et al., 2003 and Schmitt-Grohé and Uribe, 2004, 2005), the recent literature is typically based on a version of the New Keynesian model that is log-linearized around a zero inflation steady state. This paper aims to solve this inconsistency by addressing the question of how optimal monetary policy is affected by positive trend inflation.[1]

There are two important reasons why the monetary policy literature has focussed on the zero inflation steady state. The first is analytical convenience. The second is that zero inflation is optimal in a so-called cashless economy (see Goodfriend and King, 2001, and Woodford, 2003). However, quite special theoretical assumptions are needed before optimal steady-state inflation is equal to zero in any framework.

We think instead that there are compelling reasons to look at the case of *low and positive* trend inflation. First, the case of zero inflation is unrealistic in the light of the post-war economic history of industrialized countries. Schmitt-Grohé and Uribe (2004) use the average US GDP deflator growth rate in 1960-1998 to calibrate the steady state inflation rate to 4.2%. The average inflation rate for European countries in post-war years ranges from about 3% in Germany to almost 10% in Spain (OECD data). Hence, we should study optimal stabilization policy in such an environment. This is even more important if these models are used empirically to assess the behavior of central banks in the post-war period. Second, the practice of many central banks suggests that zero steady-state inflation is not their real target. In other words, zero inflation does not coincide with the concept of "price stability" held by central bankers, as the ECB case illustrates. It is therefore important to check whether results in the existing literature are robust to *moderately* positive trend inflation levels.

This article owes much to the seminal works of Clarida et al. (1999) and Galí (2003), and can be interpreted as a generalization of their findings to the case of positive trend inflation. Indeed, we provide a simple extension of their framework with the main change being an extra equation that arises when the New Keynesian Phillips Curve (NKPC) is generalized. Our model thus encompasses the standard framework, allowing us to find intuitive analytical results for the case of discretionary monetary policy, and develop straightforward comparisons with standard results.

Our main finding is that optimal monetary policy is highly sensitive to low levels of trend inflation. In particular, as trend inflation increases we find that monetary policy progressively loses its ability to stabilize inflation. The reason is that trend inflation makes firms more concerned that their prices keep up with the trend in inflation, so they are not eroded in relative terms. The optimal reset price is therefore less affected by the current level of economic activity, the NKPC is flatter, and the current output gap has less effect on current inflation. As a result, under positive trend inflation and optimal discretionary policy we find: (i) the rational expectations equilibrium (REE, henceforth) is not always determinate; (ii) the efficient policy frontier deteriorates substantially.

[1] Trend inflation is defined here as the rate of inflation in deterministic steady state.

Moreover, under positive trend inflation and optimal commitment policy we have: (i) impulse response functions and gains from commitment are highly sensitive to the level of trend inflation; (ii) interest rate smoothing increases with trend inflation. Finally, our model is able to match the positive empirical correlation between average inflation and inflation variability.

As in the standard literature, the monetary authority in our framework controls the nominal interest rate to stabilize inflation and output gap around long-run targets. We therefore ask how the optimal response to shocks is affected when trend inflation assumes empirically relevant values. Our results serve as a warning against the empirical application of existing New Keynesian models, especially versions of the models that cannot explain observed trend inflation. The trend rates of inflation we examine are, however, generally inconsistent with long-run minimization of our assumed loss function. Thus, the true extent and nature of the problem analyzed in this paper will not be known until a model is derived that can predict a positive average rate of inflation. The features that would deliver an endogenously optimal positive long-run inflation are likely to further affect the short-run Phillips curve, and may thus change the results of this paper both quantitatively and qualitatively. At the very least, though, our contribution highlights the need for such a model.

Our work is linked to some recent contributions that have appeared in the literature. Khan et al. (2003) show that the optimal long-run inflation rate is actually negative, because a negative rate balances the benefits of following the Friedman rule and the costs of relative price distortions. Schmitt-Grohé and Uribe (2005) perform a similar exercise in a medium-scale model incorporating fiscal policy and many distortions. In contrast, Schmitt-Grohé and Uribe (2004) look at optimal monetary and fiscal policy when treating the level of trend inflation as exogenously calibrated to US post-war data. Our paper is complementary to these works, but differs in two important respects. Firstly, none of the above contributions investigate how optimal monetary policy is affected by changes in trend inflation. Secondly, our framework is sufficiently tractable to deliver many analytic results, whereas the above works rely mainly on numerical results.

2 Trend Inflation and the Basic New-Keynesian Model

In this section we extend the basic New Keynesian framework of Clarida et al. (1999), Galí (2003) and Woodford (2003) to allow for positive trend inflation.

2.1 The model

Households

Households live forever and their expected lifetime utility is:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{C_t^{1-\sigma_c} - 1}{1-\sigma_c} + \chi_m \frac{(M_t/P_t)^{1-\sigma_m} - 1}{1-\sigma_m} - \chi_n N_t \right), \tag{1}$$

where $\beta \in (0,1)$ is the subjective rate of time preference and E_0 is the expectation operator conditional on time $t = 0$ information. The instantaneous utility function is increasing in the consumption of a final good (C_t) and real money balances (M_t/P_t), and decreasing in labor (N_t). The positive parameters σ_c and σ_m represent inverse intertemporal elasticities of substitution in consumption and real money balances. χ_m and χ_n are positive constants.[2] At a given period t, the representative household faces the following nominal flow budget constraint:

$$P_t C_t + M_t + B_t \leq P_t w_t N_t + M_{t-1} + (1 + i_{t-1}) B_{t-1} + D_t + T_t, \tag{2}$$

where P_t is the price of the final good, M_t is nominal money, B_t are bonds with a one-period nominal return i_t, w_t is the real wage and D_t are firm profits that are returned to households. In addition, in each period the government makes lump-sum nominal transfers to households of T_t. The household's problem is to maximize (1) subject to the sequence of budget constraints (2), yielding the following first order conditions:

$$\textit{labor supply} \quad : \quad \chi_n C_t^{\sigma_c} = w_t, \tag{3}$$

$$\textit{money demand} \quad : \quad \chi_m (M_t/P_t)^{-\sigma_m} C_t^{\sigma_c} = i_t/(1+i_t), \tag{4}$$

$$\textit{consumption Euler eq.} \quad : \quad C_t^{-\sigma_c} = \beta E_t \left[C_{t+1}^{-\sigma_c} (1+i_t) P_t/P_{t+1} \right]. \tag{5}$$

Equations (3), (4) and (5) have the usual economic interpretation.

Final good producers

In each period t, a final good Y_t is produced by perfectly competitive firms using a continuum of intermediate inputs $Y_t(i)$ and a standard CES production function $Y_t = \left[\int_0^1 Y_t(i)^{\frac{\theta-1}{\theta}} di\right]^{\frac{\theta}{\theta-1}}$, with $\theta > 1$. Taking prices as given, the final good producer chooses intermediate good quantities $Y_t(i)$ to maximize profits, resulting in the usual demand schedule: $Y_t(i) = [P_t(i)/P_t]^{-\theta} Y_t$. The zero profit condition of final good producers leads to the aggregate price index $P_t = \left[\int_0^1 P_t(i)^{1-\theta} di\right]^{\frac{1}{1-\theta}}$.

Intermediate goods producers

Intermediate inputs $Y_t(i)$ are produced by a continuum of firms $i \in [0,1]$ with technology $Y_t(i) = N_t(i)$. Prices are sticky, with intermediate goods producers in monopolistic competition setting prices according to a standard discrete-time version of the Calvo (1983) mechanism. In each period there is a fixed probability $(1-\alpha)$ that a firm can re-optimize; with probability α the firm must keep its nominal price unchanged. The problem of a price-resetting firm is thus:

$$\max_{p_t^*(i)} \quad E_t \sum_{j=0}^{\infty} \alpha^j \Delta_{t,t+j} \left[\frac{p_t^*(i)}{P_{t+j}} Y_{t+j}(i) - \Gamma_{t+j}(i) \right], \tag{6}$$

$$\text{s.t.} \quad Y_{t+j}(i) = \left[\frac{p_t^*(i)}{P_{t+j}} \right]^{-\theta} Y_{t+j}, \tag{7}$$

where $p_t^*(i)$ denotes the new optimal price, $\Gamma_{t+j}(i)$ is the real total cost function and $\Delta_{t,t+j}$ is the stochastic discount factor. The solution is a formula for the optimal reset price:

$$p_t^*(i) = \frac{\theta}{\theta-1} \frac{E_t \sum_{j=0}^{\infty} \alpha^j \Delta_{t,t+j} \left[P_{t+j}^{\theta} Y_{t+j} \Gamma'_{t+j}(i) \right]}{E_t \sum_{j=0}^{\infty} \alpha^j \Delta_{t,t+j} \left[P_{t+j}^{\theta-1} Y_{t+j} \right]}, \tag{8}$$

[2] To derive analytical results we adopt the simple Hansen (1985) indivisible labor model. Our results do not depend on this assumption.

where $\Gamma'_t(i)$ denotes the real marginal cost function.[3] To see how trend inflation affects the optimizing behavior of intermediate firms, it is useful to expand (8) and make explicit the contribution of *cumulative gross inflation rates* (CGIR, hereafter)[4] to price setting:

$$\frac{p_t^*(i)}{P_t} = \frac{\theta}{\theta-1}\frac{E_t\sum_{j=0}^{\infty}\alpha^j\Delta_{t,t+j}Y_{t+j}\left[(\Pi_{t+1}\times\Pi_{t+2}\times\cdots\times\Pi_{t+j})^{\theta}\,\Gamma'_{t+j}(i)\right]}{E_t\sum_{j=0}^{\infty}\alpha^j\Delta_{t,t+j}Y_{t+j}\left[(\Pi_{t+1}\times\Pi_{t+2}\times\cdots\times\Pi_{t+j})^{\theta-1}\right]}. \tag{9}$$

It is insightful at this stage to look at the steady-state behavior of (9) by setting $\Pi_{t+j}=\gamma$ for $j=1,2,\cdots,\infty$. Then, in the standard case of zero trend inflation, $\gamma=1$ and the CGIRs attached to future expected terms are equal to one at all times. Future expected terms are discounted by $\alpha\beta$. With positive trend inflation, $\gamma>1$ and two effects come into play. First, CGIRs at different time horizons shift upwards, which changes the effective discount factors $\alpha\beta\gamma^{\theta}$ and $\alpha\beta\gamma^{\theta-1}$ in the numerator and denominator respectively. Accordingly, when intermediate firms are free to adjust they will set higher prices to try to offset the erosion of relative prices and profits that trend inflation automatically creates. Second, future terms in (9) are progressively multiplied by larger CGIRs. This means that optimal price-setting under trend inflation reflects future economic conditions more than short-run cyclical variations. Price-setting firms become more "forward-looking", as does inflation. These effects are the main driving force behind our results.

Government

The government injects money into the economy through nominal transfers, so $T_t = M_t^s - M_{t-1}^s$ where M^s is aggregate nominal money supply. Most importantly, we assume that steady-state money supply evolves according to the following fixed rule: $M_t^s = \gamma M_{t-1}^s$, where γ is the (gross) steady-state growth rate of the nominal money supply.

Market clearing conditions

The market clearing conditions in the goods, money and labour markets are: $Y_t = C_t$; $Y_t^s(i) = Y_t^D(i) = [P_t(i)/P_t]^{-\theta}Y_t$, $\forall i$; $M_t = M_t^s$ and $N_t = \int_0^1 N_t(i)di$ respectively.

2.2 A generalized New Keynesian Phillips Curve

Log-linearizing (4) and (5), and using the market clearing condition $\hat{Y}_t = \hat{C}_t$, we obtain:

$$\beta\hat{\imath}_t = -\sigma_m(\gamma-\beta)\hat{m}_t + \sigma_c(\gamma-\beta)\hat{Y}_t, \tag{10}$$

$$\hat{Y}_t = E_t\hat{Y}_{t+1} - \sigma_c^{-1}(\hat{\imath}_t - E_t\hat{\pi}_{t+1}), \tag{11}$$

where hatted variables denote percentage deviations from the deterministic steady state.

The log-linearization of equation (8) leads to a system of two first-order expectational difference equations that characterize the generalized NKPC under trend inflation:

[3] In a deterministic steady state the infinite sums in equation (8) converge if and only if $\alpha\beta\gamma^{\theta}<1$ (see Ascari, 2004). In what follows we assume that this condition holds. For the benchmark calibration values in Table 1, it implies that annual trend inflation has to be lower than 11.4%.

[4] We define the CGIR between time $t+1$ and $t+j$ as $\Pi_{t+1,t+j} = \Pi_{t+1}\times\Pi_{t+2}\times\cdots\times\Pi_{t+j}$, where $\Pi_{t+j} = P_{t+j}/P_{t+j-1}$. Note that CGIRs are raised to the power θ in the numerator and $\theta-1$ in the denominator.

$$\begin{cases} \hat{\pi}_t = \kappa \hat{Y}_t + \beta\gamma E_t \hat{\pi}_{t+1} + (\gamma - 1)\,\beta\left(1 - \alpha\gamma^{\theta-1}\right) E_t\left[(\theta-1)\,\hat{\pi}_{t+1} + \hat{\phi}_{t+1}\right] \\ \hat{\phi}_t = \left(1 - \alpha\beta\gamma^{\theta-1}\right)(1 - \sigma_c)\,\hat{Y}_t + \alpha\beta\gamma^{\theta-1} E_t\left[(\theta-1)\,\hat{\pi}_{t+1} + \hat{\phi}_{t+1}\right] \end{cases} \quad (12)$$

where $\kappa \equiv (\gamma - 1)(\sigma_c - 1)\,\beta\left(1 - \alpha\gamma^{\theta-1}\right) + \sigma_c \bar{\lambda}(\gamma)$, $\bar{\lambda}(\gamma) \equiv \frac{\left(1-\alpha\gamma^{\theta-1}\right)\left(1-\alpha\beta\gamma^{\theta}\right)}{\alpha\gamma^{\theta-1}}$ and $\hat{\phi}_t$ is an auxiliary variable with no obvious interpretation. Our generalization encompasses the standard NKPC. Indeed, when $\gamma = 1$ equation (12) reduces to $\hat{\pi}_t = \beta E_t \hat{\pi}_{t+1} + \frac{(1-\alpha)(1-\alpha\beta)\sigma_c}{\alpha}\hat{Y}_t$ and the auxiliary variable $\hat{\phi}_t$ is irrelevant for inflation dynamics.

Three points are worth stressing. Firstly, trend inflation dramatically alters the dynamics of inflation compared to the usual Calvo model with $\gamma = 1$. The elasticity κ of inflation to the current output gap in (12) is now a function of γ as well as the usual α, β, θ and σ_c. For standard calibration values, trend inflation leads to a smaller coefficient on the current output gap and larger coefficients on future expected inflation and $E_t\hat{\phi}_{t+1}$. In other words, trend inflation flattens the short-run NKPC. For given future expectations, current inflation reacts less to a given change in current output (or current output has to move more to cause a given change in current inflation). The intuition behind this result is the way intermediate firms become more forward-looking when setting prices under trend inflation, as explained in section 2.1 As trend inflation increases, future economic conditions carry more weight and current output becomes less important as a determinant of reset prices. The contemporaneous relation between $\hat{\pi}_t$ and $\hat{Y}_t$ progressively weakens and the inflation rate becomes less sensitive to variations in the output gap.

Secondly, the system of equations (11) and (12) represents a compact generalization of the standard New Keynesian model. The NKPC under trend inflation is defined simply by adding an additional equation that explains the evolution of the auxiliary variable $\hat{\phi}_t$.

Thirdly, in what follows we assume log-utility in consumption so $\sigma_c \to 1$. The equation for $\hat{\phi}_t$ then depends only on future expected variables and can be ignored under discretionary policy.

2.3 Transmission of monetary policy shocks

This section analyses the monetary policy transmission mechanism when the money supply growth rate is assumed to follow an exogenous AR(1) process. Table 1 shows the benchmark calibration and parameter values are as in Galí (2003).[5] Figure 1 displays impulse responses functions (IRFs, hereafter) for the responses of output gap, inflation, real interest rate and real money balances to a unit shock to the growth rate of money. Each panel shows IRFs for six levels of trend inflation: 0, 2%, 4%, 6%, 8% and 10%.

Consider first the case of zero steady-state inflation. In response to the money supply growth rate shock, sluggish adjustment of individual prices leads to a gradual upward adjustment of the aggregate price level, thereby causing an increase in both inflation

[5] The persistence parameter of the money supply growth rate process is set to 0.5, as in Galí (2003). Moreover, changes in the values of θ and σ_c have similar effects in our model to those in a standard model (see equation (12)). We only present results for the benchmark calibration since the qualitative effects of trend inflation do not depend on the precise values of calibrated parameters.

and real money balances. Output and the nominal interest rate need to adjust to satisfy the money demand equation (10). If we assume momentarily that money demand is interest inelastic (i.e., a quantity theory money demand), the persistent increase in money growth leads to higher expected inflation in the future and a long period of negative (ex-ante) real interest rates. Given the Euler equation (11), households bring forward consumption; demand and output both increase. Indeed, solving the Euler equation forward shows $\hat{Y}_t = -\sigma_c^{-1} E_t \sum_{i=0}^{\infty} (\hat{\imath}_{t+i} - \hat{\pi}_{t+1+i})$ and the output effect is defined by the extent to which the money supply growth rate shock influences current and future short-term expected real interest rates. For our benchmark calibration, the rise in output on impact is so high that equation (10) requires the nominal interest rate to jump up rather than down after a positive money shock.[6] On impact, output jumps by 1.48% and inflation by 2%, with both progressively returning to steady state values as prices sluggishly adjust.

With the discussion of section 2.3 in mind, it is easy to explain why trend inflation has such a notable effect on the impulse response functions in Figure 1. Specifically, trend inflation causes newly reset prices to be less sensitive to current economic conditions, so money supply growth shocks have a larger effect on real money balances as the level of trend inflation rises. The output gap response similarly increases to satisfy the money demand and Euler equations. The inflation response decreases.

There is also a second effect of higher trend inflation in that the persistence of the output and inflation IRFs increases substantially. As shown in Table 2, the half-life of both output and inflation is 3.5 quarters when steady-state inflation is zero, but rises to 8.7 for output and 8.3 for inflation when steady-state inflation is 10%. The intuition for this is again the effect that trend inflation has on the output-inflation trade-off. It is important to stress that modifying the NKPC to allow for trend inflation leads to substantial changes in the dynamics of the model.[7]

3 Optimal Monetary Policy Under Discretion

As in Clarida et al. (1999) and Galí (2003), we assume that the monetary authority sets the nominal interest rate to minimize a discounted sum of expected instantaneous loss functions, defined over inflation and output gap according to:

$$\mathcal{W} = \frac{1}{2} E_t \sum_{j=0}^{\infty} \beta^j \left(\hat{\pi}_{t+j}^2 + \chi \hat{Y}_{t+j}^2 \right) \tag{13}$$

where χ is the relative weight placed on output gap stabilization. We also follow Clarida et al. (1999) and Galí (2003) by adding a cost-push shock $u_t = \rho u_{t-1} + \varepsilon_t$; $\varepsilon_t \sim$ i.i.d. $N(0,1)$ to the first equation in (12). The policy problem is to choose the optimal nominal interest rate path that minimizes (13), subject to the IS curve (11) and the NKPC (12).

Under discretion, the monetary authority is unable to make credible announcements about future policy actions. Thus, it re-optimizes (13) each period taking future expec-

[6] See Galí (2003) on the lack of liquidity effect in this type of model.

[7] Ascari and Ropele (2005) study the dynamic properties of this model when monetary policy is implemented by a Taylor interest rate rule. See also Amano et al. (2005).

tations as given. The solution is:

$$\hat{Y}_t = -\frac{\bar{\lambda}(\gamma)}{\chi}\hat{\pi}_t. \tag{14}$$

The prescription is thus for discretionary policy to "lean against the wind". The solution is very similar to the standard one obtained with zero steady-state inflation. There is, however, a crucial difference in that the "aggressiveness" with which the output gap responds to inflation is now dependent on the level of trend inflation. The higher trend inflation, the less aggressively the monetary authority fights inflation and the more output is stabilized. This is due to the change in the slope of the short-run NKPC, whereby higher trend inflation lowers the gain in terms of reduced inflation for each unit of output loss, i.e., $\bar{\lambda}(\gamma)$ is a decreasing function of γ. The worsening of the inflation-output trade-off induces a less aggressive policy response to inflation, making shocks pass through more into inflation than output, and increasing the relative variability of inflation (σ_π/σ_Y).

This result also has an appealing empirical implication in that it implies a positive correlation between average inflation and the variance of inflation. Such a correlation has robust empirical support, both over time and across countries (see, e.g., Friedman, 1977, Ball and Cecchetti, 1990, and Caporale and McKiernan, 1997). We stress that our positive correlation between γ and σ_π stems from the optimal response of monetary policy.

3.1 An indeterminacy problem

Substituting condition (14) into (12), the system can be solved for $\hat{\pi}_t$ and $\hat{\phi}_t$ as a function of the only state variable u_t. $\hat{Y}_t$ and $\hat{\imath}_t$ are then determined by (14) and the IS curve respectively. However, when $\gamma \in \left[1, (1/\alpha\beta)^{1/\theta}\right)$ there is a potential problem with uniqueness of the REE.

Proposition 1 *Let $\sigma_c = \beta = 1$. The dynamic system defined by optimal monetary policy under discretion admits a unique REE if and only if:*

$$\frac{\chi\theta(\gamma-1)}{\left[\bar{\lambda}(\gamma)\right]^2} < 1. \tag{15}$$

It follows that large values of γ lead to an indeterminate REE, whereas indeterminacy never arises with the standard assumption of zero trend inflation (i.e., $\gamma = 1$).[8] However, for any (admissible) value of trend inflation there is always a sufficiently low value of χ to ensure the REE is unique.[9] In other words, the higher the value of trend inflation the more "conservative" a central bank needs to be to guarantee uniqueness of REE under optimal discretionary policy.

Figure 2 shows the combinations of (γ, χ) that ensure uniqueness of the REE with the benchmark calibration of Table 1, for $\gamma \in [1, 1.02]$ and $\chi \in [0, 1]$. Three things are

[8] Ceteris paribus, indeterminacy is more likely to arise (i) the higher the level of trend inflation γ; (ii) the higher the elasticity of substitution among goods θ; (iii) the higher the weight on output in the monetary authority loss function χ; (iv) the higher the probability of not adjusting prices α.

[9] $\bar{\lambda}(\gamma)$ tends to zero as γ tends to its upper bound (defined by the condition $\alpha\beta\gamma^\theta < 1$), so it always has finite value within the range of admissible values of γ.

of note. Firstly, a 2% inflation rate target of the type announced by the ECB requires a value of χ lower than 0.078 to ensure determinacy. That is, the weight on inflation fluctuations needs to be at least ten times higher than that on output fluctuations. Secondly, Galí (2003) calibrates the value of χ as 0.0078 in a theoretical model. In this case, only annual levels of trend inflation lower than 4.7 % (i.e., $\gamma = 1.0116$) can support determinacy. Thirdly, Schmitt-Grohé and Uribe (2004) calibrate trend inflation as 4.2% to match the U.S. average GDP deflator growth rate over the period 1960-1989. Here, determinacy requires the Fed's weight on inflation to be roughly seventy-seven times higher than that on output fluctuations.

Figure 2 casts additional shadows on the monetary policy of many developed countries in the 70's and 80's, when the level of trend inflation was so high that determinacy would have required central bankers to be almost pure inflation targeters. If we are willing to assume that central banks at the time had no commitment power and were not pure inflation targeters (see, e.g., Clarida et al., 1999), then the natural conclusion is that monetary policy was simply not implementable during that period. Indeed, in many countries inflation got out of hand after the oil shocks of the 70's.

3.2 The efficient frontier

The case of a purely transitory cost push shock yields the following analytical closed form solution:

$$\hat{Y}_t = -\hat{\imath}_t = -\frac{\bar{\lambda}(\gamma)}{\bar{\lambda}(\gamma)^2 + \chi} u_t \qquad \text{and} \qquad \hat{\pi}_t = \frac{\chi}{\bar{\lambda}(\gamma)^2 + \chi} u_t. \tag{16}$$

Note that (16) exactly parallels the solutions in Clarida et al. (1999) (i.e., equations (3.4) and (3.5) on p. 1672) and Galí (2003) (i.e., equations (39) and (40)). However, in our generalized case the optimal split of the shock between inflation and output depends on trend inflation (through $\bar{\lambda}(\gamma)$) as well as the loss function parameter χ.

Proposition 2 *As trend inflation increases, inflation reacts more to the cost push shock. The reaction of output is ambiguous, since it depends on the relative gains and costs to stabilization, as measured by χ and $\bar{\lambda}(\gamma)$.*

Inflation reacts more because the degree to which a contraction of the output gap reduces inflation is decreasing in trend inflation, so the current output cost of a given reduction in inflation is increasing in the level of trend inflation. To understand the ambiguity of the output response note that $\frac{\partial \hat{\imath}_t}{\partial \gamma} < 0$ if $\chi > 2\bar{\lambda}(\gamma)$, and assume that $\chi < 2\bar{\lambda}(1)$ for zero trend inflation as in the benchmark calibration. As trend inflation increases, the response of monetary policy is first more aggressive (i.e., $\frac{\partial \hat{\imath}_t}{\partial \gamma} > 0$), but then starts to become more passive as $\bar{\lambda}(\gamma)$ falls and the above condition switches sign to $\frac{\partial \hat{\imath}_t}{\partial \gamma} < 0$. In the benchmark calibration, the switch in sign happens at less than 1% annual inflation. The reason for the switching is that the interest rate is a weaker policy instrument in the presence of trend inflation. Up to a certain point the monetary authority uses it more heavily, but then the optimal response is increasingly cautious and passive.

This behavior is also reflected in the efficient policy frontier that links output and inflation variability for different values of χ in (13).

Proposition 3 *Let* $\rho = 0$ *and* $\sigma_\varepsilon = 1$ *so the efficient policy frontier is given by* $\sigma_Y = 1/\bar{\lambda}(\gamma) - \sigma_\pi/\bar{\lambda}(\gamma)$. *As trend inflation increases, the efficient policy frontier becomes steeper and moves to the north-east.*

Points on the zero trend inflation frontier are no longer possible as γ rises, so there must be an increase in σ_Y and/or σ_π as trend inflation increases. Figure 3 shows efficient policy frontiers for the case $\rho = 0.5$, with each line corresponding to a different value of trend inflation. To understand how the figure is constructed, consider the black line with circles that displays the output-inflation variability frontier under zero trend inflation. Any given value of χ is associated with a particular combination of σ_Y and σ_π, and hence a circle on the line. By increasing χ from 0 to 1 (in steps of 0.01) the circle moves from left to right and traces out the efficient policy frontier. Figure 3 shows that output (inflation) variability monotonically decreases (increases) as χ rises. The figure also illustrates that trend inflation tilts the efficient policy frontiers upwards to the north-east, leading to worse outcomes for both inflation and output variability. For instance, the points attainable with 2% trend inflation (the black line with stars) are no longer attainable with 4% trend inflation (the black line with diamonds). Moreover, the number of points that composes the frontier decreases with γ, because fewer values of χ prevent the model to enter the indeterminacy region when trend inflation is high (see Figure 2). Finally, most of the points on the efficient policy frontiers are clustered in the lower right corner, suggesting that only very low values of χ can deliver low values of inflation variability. In summary, as trend inflation increases the frontier tilts upwards, becomes steeper and gets shorter.

4 Optimal Monetary Policy Under Commitment

In the presence of a credible commitment mechanism, the monetary authority recognizes that its policy actions influence agents' expectations. In this case, it is not possible to derive analytical results so the model is solved numerically. The two main findings are:

Result 1. *Let* $\chi \in [0, 1]$ *and* $\gamma \in [1, 1.03]$. *The REE is always determinate under commitment.*[10]

Result 2. *The persistence of the optimal response of the nominal interest rate to a cost-push shock is positively correlated with the level of trend inflation.*

It is well known that optimal monetary policy shows a certain degree of inertia under commitment (see Woodford, 1999). Our numerical results show that optimal monetary policy inertia, as proxied by the magnitude of the stable eigenvalues, increases with trend inflation. The intuition rests on the impact of trend inflation on the NKPC. Firstly, trend inflation makes the NKPC more forward-looking and thus reinforces the incentive to use policy persistence to influence future expectations. Secondly, we saw in section 2.3 that the transmission mechanism itself becomes more inertial under trend inflation, since current inflation becomes less responsive to the output gap.

Response to a cost push shock

We now analyze IRFs of the output gap, inflation rate, nominal interest rate and

[10] For robustness, we considered sensitivity of the results to different parametrizations of the intertemporal elasticity of substitution (i.e., $\sigma_c = 5$) and the degree of nominal stickiness (i.e., $\alpha = 0.5$).

real interest rate to a unit cost-push shock under commitment.[11] In each case we retain the benchmark parameterization of Table 1 and set $\chi = 0.0078$ following Galí (2003).

Figure 4 displays the IRFs for a purely transitory cost-push shock. In the standard zero steady-state inflation case, the monetary authority responds to a cost-push shock by raising the nominal interest rate above steady state for a few quarters, thereby creating prolonged adjustment of the output gap and an aggressive deflation. As is well known, the reaction of the interest rate and output gap are smaller but more persistent than under discretion. Indeed, forward-looking price setters are reluctant to raise prices after a cost-push shock if they expect the monetary authority to respond with a protracted period of tight policy.

The introduction of trend inflation has substantial qualitative and quantitative effects on the IRFs. Recall that trend inflation makes price setters more forward-looking (see Section 2.2) and monetary policy less effective. When inflation dynamics are more forward-looking there are greater incentives for the monetary authority to influence expectations, so we expect a strengthening of typical optimal commitment policy features such as lower impact effects and greater persistence. With monetary policy less effective, we expect monetary policy to react less aggressively. The increase in forward-looking behavior and loss of effectiveness both point towards a decrease in the impact multipliers on $\hat{\imath}$ and $\hat{Y}$, while the extra forward-lookingness suggests a higher degree of inertia. Figure 4 illustrates that this is indeed the case, with higher levels of trend inflation smoothing the IRFs and dampening the impact effects. For levels of trend inflation up to 6% the pattern of the endogenous variables is intuitively plausible. For 8% or 10% trend inflation the dynamics properties of the system become quite striking. At these high levels of trend inflation the reduction in inflation per unit of output loss is very low, and the policy maker finds it optimal to keep the output gap almost constant. The interest rate is set slightly above expected future inflation, producing obvious volatility in inflation.

Gains from commitment

To assess the welfare implications of trend inflation, we calculate the unconditional loss $E(W) = Var(\hat{\pi}_t) + \chi Var(\hat{Y}_t)$ under commitment and discretion, together with the percentage gain from commitment $100 \times (1 - L_c/L_d)$. L_c and L_d denote the losses under commitment and discretion respectively. Table 3 reports the results.

Several features are worthy of note. Firstly, discretion always leads to greater expected welfare losses than commitment, since under discretion the monetary authority lacks the capacity to influence future expectations. Secondly, welfare losses increase with trend inflation under both discretion and commitment, regardless of the persistence of shocks. In comparison to a policy that targets zero inflation, a policy that targets 2% inflation (as the stability-oriented policy announced by the ECB supposedly does) involves a remarkable percentage loss in welfare. Hence, even very low levels of trend inflation do substantial harm to the performance of optimal monetary policy. Thirdly, the last column of Table 3 reports the percentage gain from commitment. Given that trend inflation increases the importance of influencing future expectations, one might expect the gains to commitment to be increasing in trend inflation. This is true only for moderate levels of trend inflation. For example, when $\rho = 0$ the percentage gain to commitment is increasing in trend inflation up to an annual rate of 2.4%. After this the gain

[11] In computing impulse response functions we follow the approach of Soderlind (1999).

remains positive but starts to decline. With $\rho = 0.5$ the threshold level of trend inflation is 4.8%. This finding derives from the second effect of positive trend inflation, namely that it reduces the effectiveness of monetary policy. At high levels of trend inflation the effectiveness of policy is reduced to such an extent that inflation becomes very costly to control. Policies under commitment and discretion become similar as they both begin to disregard inflation and the gain to commitment is reduced. This result is apparent in the behavior of the unconditional variances of $\hat{\pi}$ and $\hat{Y}$. Fourthly, Table 3 shows that persistence in the shock tends to increase the percentage gains to commitment.

Finally, in separate calculations we analyzed the robustness of our results to two extensions of the basic model: (*i*) elastic labor supply; (*ii*) strategic complementarities arising from sector-specific labor markets. All the above results are robust to these modifications, with quantitatively stronger effects particularly apparent when strategic complementaries are introduced.[12]

5 Conclusions

With significant levels of post-war inflation in developed countries and central banks typically targeting positive rates of inflation, it is somewhat surprising that the monetary policy literature has taken zero inflation steady-state models as a benchmark. We think it is very important that the main model in the literature is robust to allowing for positive trend inflation level.

The contribution we make is to extend the seminal model of Clarida et al. (1999) and Galí (2003) to allow for a generic steady-state inflation rate. The resulting simple framework is tractable and encompasses existing models as a special case. Our main finding is that optimal monetary policy is highly sensitive to the level of trend inflation. In particular, monetary policy becomes less effective at stabilizing the economy once trend inflation increases. This occurs because trend inflation flattens the NKPC and makes inflation less responsive to the output gap. Moreover, under discretion the rational expectations equilibrium is not always determinate and the efficient policy frontier deteriorates substantially. Under commitment, interest rate smoothing increases as trend inflation rises. More generally, impulse responses and gains to commitment are highly sensitive to the level of trend inflation.

Our results are naturally sensitive to the assumptions of no indexation and fixed contract length in the standard model. A relaxation of either of these would weaken our conclusions. With respect to the no-indexation assumption, Ascari (2004) shows that indexation reduces the effect that trend inflation has on the NKPC. In the limit, full indexation removes the effect completely. However, we stress that our concern is with low levels of trend inflation such as those observed post-war in developed countries, in which case the sticky price assumption is reasonable. Moreover, (i) in reality we do not observe indexed prices; (ii) we have known that full indexation is not optimal since at least Gray (1976); (iii) the theoretical microfoundations of price indexation schemes are rather questionable; and (iv) the main justification for price indexation in studies such as Christiano et al. (2005) is empirical not theoretical. With respect to the fixed

[12] All calculations appear in the working paper version of this article, available on the websites of the authors.

contract length assumption, we find it reasonable to fix the expected duration of prices exogenously for moderate levels of trend inflation.

More generally, our results serve as a warning against the use of existing New Keynesian models in empirical analysis of postwar data. It is preferable to work with models such as ours that properly account for trend inflation. However, an issue remains in that the levels of trend inflation we examine are inconsistent with long-run maximization of our assumed loss function. We acknowledge this problem, but see it as highlighting the pressing need for models that endogenously deliver optimal long-run inflation rates that are positive. Such models are likely to have even greater modifications of the short-run NKPC, and may lead to both quantitatively and qualitatively different results.

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6 Tables

Parameter	β	σ_c	σ_m	α	θ
Value	0.99	1	1	0.75	11

Table 1: Benchmark Calibration (quarterly)

Annual Trend Inflation	0%	2%	4%	6%	8%	10%
Output Half Life	3.5	3.9	4.4	5.1	6.3	8.7
Inflation Half Life	3.5	3.8	4.3	5	6.1	8.3

Table 2: Half-Life of Output and Inflation (quarters)

Parameter values		Discretion			Commitment			%Gain
γ	ρ	Var($\hat{\pi}_t$)	Var($\hat{Y}_t$)	Loss	Var($\hat{\pi}_t$)	Var($\hat{Y}_t$)	Loss	
1	0	0.265	32.025	0.514	0.222	22.096	0.394	23.397
1.005	0	0.489	26.949	0.699	0.361	20.411	0.520	25.609
1.01	0	0.741	15.373	0.861	0.530	15.302	0.649	24.601
1.015	0	0.916	5.248	0.957	0.692	7.766	0.753	21.333
1.02	0	0.987	0.842	0.993	0.795	1.605	0.807	18.743
1.025	0	1	0.019	1	0.839	0.044	0.840	16.016
1	0.5	0.635	76.843	1.234	0.283	67.597	0.811	34.313
1.005	0.5	1.563	86.1	2.235	0.605	84.986	1.268	43.243
1.01	0.5	3.18	65.992	3.695	1.216	89.19	1.912	48.256
1.015	0.5	4.831	27.669	5.047	2.151	60.169	2.620	48.08
1.02	0.5	5.639	4.809	5.677	2.956	14.213	3.067	45.973
1.025	0.5	5.707	0.108	5.708	3.369	0.425	3.372	40.922

Table 3. Welfare Analysis.

7 Figures

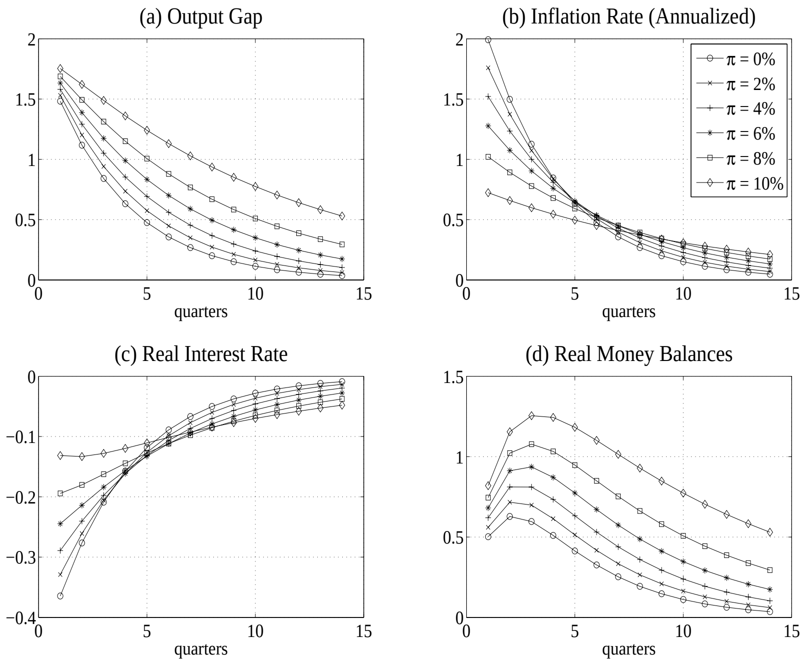

Figure 1. Impulse responses functions to a money supply growth rate shock.

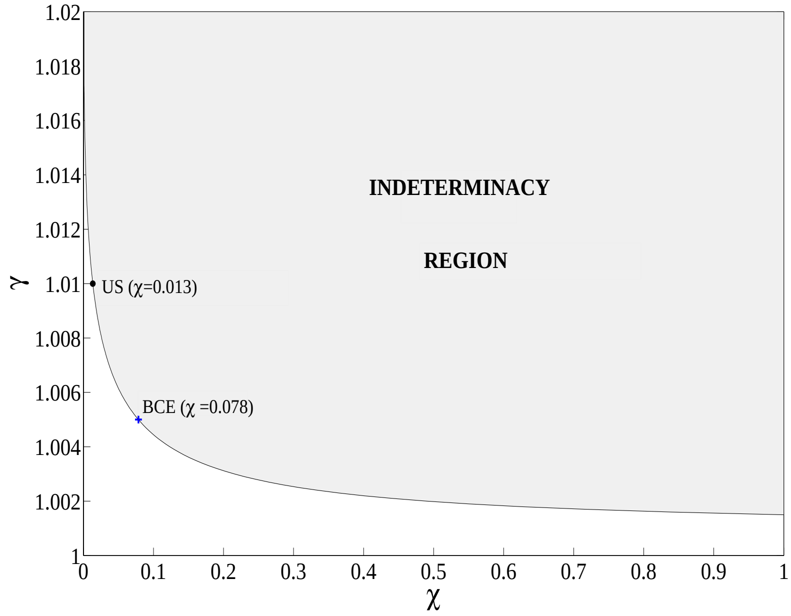

Figure 2. The indeterminacy region as a function of γ and χ.

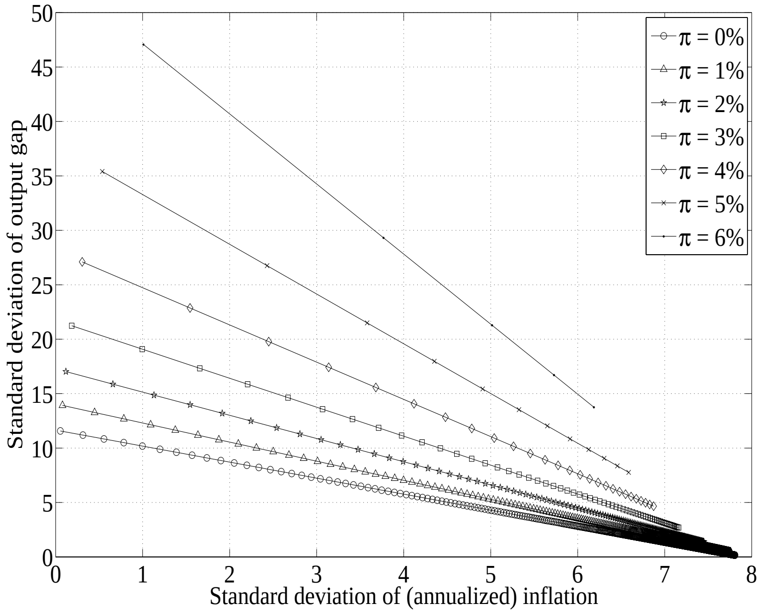

Figure 3. Efficient frontier as a function of trend inflation ($\rho = 0.5$).

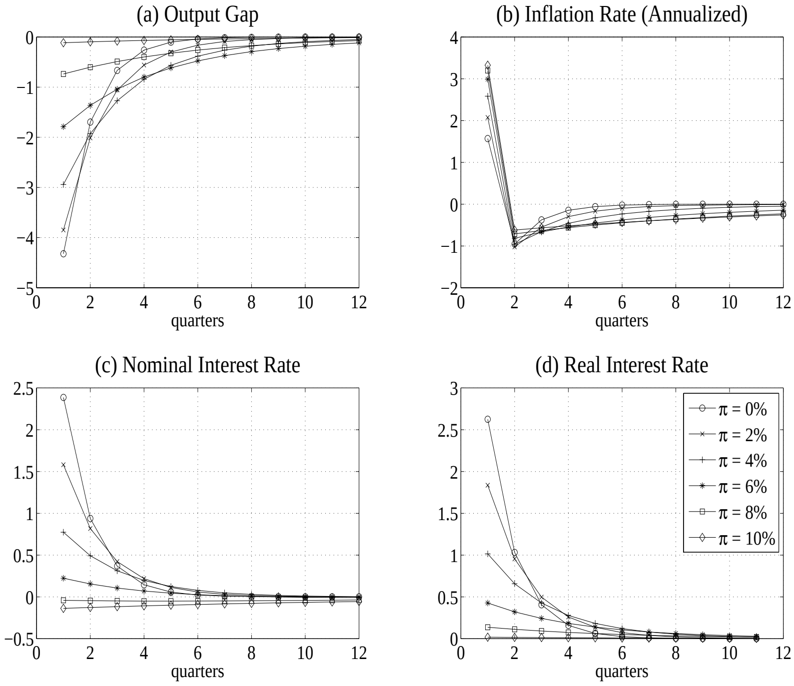

Figure 4. Optimal impulse responses under commitment ($\rho = 0$)

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