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Transmission Lags and Optimal Monetary Policy

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Abstract

The credibility problems of monetary policy are enlarged by transmission lags whenever the welfare criterion consists of arguments with differing transmission lags. If, as usually argued, prices react to monetary policy with a longer lag than output, the discretionary bias is substantially increased under a consumer welfare maximizing policy criterion (flexible inflation targeting) in the prototype New Keynesian model. Money growth targeting can significantly reduce the discretionary bias, but is not robust to other specifications of welfare with higher valuation of output stability.

Key words: discretion and stabilization bias, monetary policy, transmission lags, inflation targeting, money targeting.

JEL classification: E52; E58; E61

1. Introduction

Since Kydland and Prescott (1977) and Barro and Gordon (1983) we have known that an overly ambitious monetary policy which aims to bring output above the natural level is associated with inflation and stabilization biases. If the central bank tries to systematically exploit the short-run trade off between output and inflation, it will lead to higher inflation, and output and inflation being stabilized sub-optimally. Furthermore, due to the lack of commitment to future policies, discretionary policymaking is unable to appropriately influence expectations about the future. At the time policy is implemented, the advantages of the future commitment may already have been realized and the policymaker has incentives to deviate from the pre-announced policy. In the absence of commitment technology, the best thing a policymaker can do is to re-optimize policy in every period. Since people form expectations rationally, this will be anticipated and the only equilibrium is that of the time-consistent optimal discretionary equilibrium which may perform considerably worse than the optimal commitment policy.

This paper studies the impact of delayed effects of monetary policy on the economy in the discretionary equilibrium. Delayed effects are commonly referred to as the transmission lags of monetary policy. It is almost universally accepted that monetary policy

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is subject to rather long transmission lags and that they create various challenges for monetary policy. In this paper we show that if the transmission lags are caused by implementation lags in the private sector, the credibility problems of a welfare-maximizing policymaker that acts under discretion increase. Under the reasonable assumption that pricing decisions of the firms are subject to longer implementation lags than household consumption decisions, the discretionary policy involves no policy-induced stabilization of cost-push shocks in the canonical New Keynesian model.¹ The argument is simple: at the horizon the policymaker can affect output gap, inflation (and prices) are already pre-determined. The best discretionary policy is then to fully stabilize the output gap. The implementation lags have a severe impact on the discretionary equilibrium in particular if the cost-push shocks are persistent.

We argue that when society attaches little weight on output stabilisation, adopting a single target for monetary policy, thus having a strict (as opposed to flexible) monetary policy, eliminates the additional credibility problems caused by differing transmission lags. The central bank does not get tempted in deviating from the main nominal target. Our result confirms the results in Söderström (2005) who argues that there is a role for money growth targeting in reducing the discretionary bias. We also show that the relative benefits of money growth targeting over inflation increases when there is an implementation lag in prices. Our results support the Friedman (1960) conjecture that lags in the transmission mechanism could be a reason for adopting money growth targeting, yet this result is not robust to alternative specifications of welfare with higher valuation of output stability. Furthermore, the argument for money growth targeting should be balanced by the potential for instability of money demand.

The remainder of the paper is organized as follows. Section 2 present the canonical New Keynesian model and section 3 derives the optimal discretionary policy strategies under both discretion and commitment. Section 4 discusses most important alternative policy regimes that offer a potential remedy to discretionary bias. Welfare comparisons are then made in Section 5. Section 6 concludes.

2. The model

The private-sector pricing decisions are carried out within the Calvo (1983) framework. In each period the firm has a fixed probability of changing its price. The firm sets prices in order to maximize profits under the condition that it might not be able to adjust prices in the next period. In addition, we assume that there is a j -period implementation lag of prices, i.e. prices are set in advance of the actual implementation. This could be due to staggering of wage and/or price contracts or because of information delays.² This leads to the New Keynesian Phillips curve (see Roberts (1995) and Woodford (2003))

¹See Goodfriend and King (1997), Rotemberg and Woodford (1997), McCallum and Nelson (1999) and Clarida et al. (1999).

²An alternative way of introducing inertia in pricing behavior is to combine Calvo (1983) framework with indexation. In this approach, firms that are not allowed to optimise, set their prices on the basis of lagged aggregate prices (e.g. Galí and Gertler, 1999), or own lagged prices (e.g. Christiano et.al, 2005), plus the product of an indexing parameter and lagged inflation. This gives rise to a lagged inflation term in the NK Phillips curve. Our framework emphasizes information delays as another and possibly complementing explanation of the lagged effect of monetary policy on prices.

given by

$$\pi_{t+j} = \delta\pi_{t+j+1|t} + \gamma x_{t+j|t} + \varepsilon_{t+j}, \quad (1)$$

where $\pi_{t+j} \equiv p_{t+j} - p_{t+j-1}$ is inflation at time $t+j$, $x_{t+j|t}$ is the output gap at time $t+j$, δ is the representative agent's discount factor and ε_{t+j} is a cost-push shock that represents other factors that influence price setting at time $t+j$, not considered at time t .³ These factors can be surprise movements in the mark-up of prices.⁴ The parameter γ is a convolution of the model's deep parameters and it captures a sensitivity of inflation to output gap.

The Euler consumption equation, when combined appropriately with the households' labour supply choice and product market equilibrium condition, gives rise to an expectational IS-curve of the form (see, e.g., Rotemberg and Woodford (1997), McCallum and Nelson (1999) and Woodford (2003))

$$x_{t+m} = x_{t+m+1|t} - \sigma (i_{t+m|t} - \pi_{t+m+1|t} - r_{t+m}^n), \quad (2)$$

in case where there is an m -period implementation lag in consumption decisions.⁵ r_{t+m}^n denotes the natural real interest rate at time $t+m$ and is taken as exogenous process by households. σ is the intertemporal elasticity of substitution. Consumption and pricing decisions being predetermined for some period of time implies that inflation and output are less forward looking than in the standard NK model.

The model has been extensively studied by Woodford (2003) and Clarida et al. (1999), and by Svensson and Woodford (2005) in the case of $j = m = 1$ period implementation lags. Furthermore, Woodford (2003, chapter 8) studies the case with $j = m = s$, where s is any arbitrary, positive number. In this paper, we assume that $j \geq m$, i.e. that the implementation lag of prices may be either longer or equal to that of output gap. Based on evidence from VAR models (e.g., Christiano et al., 2005) and other empirical models (e.g., Rudebusch, 2002a,b), it is in fact reasonable to assume that inflation and output gap respond to changes in monetary policy with different delays. Such differences in delays are also featured in several theoretical models of the monetary transmission mechanism (see, e.g., Svensson, 1997). The traditional forward-looking New Keynesian Phillips curve without implementation lags suggests that inflation responds simultaneously with changes in output gap. Considering the empirical evidence, such a feature seems unrealistic and any policy advice hinging on this could be problematic. By allowing for implementation lags, however, the NK model can generate plausible equilibrium responses where output gap precedes inflation movements, see, e.g. Woodford (2003, section 3.12).

³For any variable z , we use the notation that $z_{t+d|t} \equiv E_t z_{t+d}$, where E_t is mathematical expectation operator, t denotes the time when expectations are formed and d is it the time forward operator.

⁴We follow Svensson and Woodford (2005) in assuming that the cost-push shock has an immediate influence on pricing. Note that this assumption is not important for the conclusions regarding the credibility problems of monetary policy in this paper.

⁵Woodford (2003, ch. 5) provides detailed discussion on complications that may arise from combining the models where consumption and pricing behavior are subject to decision lags in NK framework. Our setup here is consistent with microfoundations to the extent that we have assumed $j \geq m$.

3. The welfare maximizing monetary policy

We study first the monetary policy regime where the central bank maximizes welfare directly. In this framework, the central bank's dynamic optimization problem can be written as

$$\begin{aligned} \min_{\{i_{t+m|t}\}_{t=t_0}^{\infty}} E_{t_0} \sum_{t=t_0}^{\infty} \delta^{t-t_0} L_t \\ \text{s.t.} \\ \pi_{t+j} &= \delta \pi_{t+j+1|t} + \gamma x_{t+j|t} + \varepsilon_{t+j}, \\ x_{t+m} &= x_{t+m+1|t} - \sigma (i_{t+m|t} - \pi_{t+m+1|t} - r_{t+m}^n), \end{aligned} \quad (3)$$

and where

$$L_t = \pi_t^2 + \lambda x_t^2 \quad (4)$$

is the period social loss function and $E_{t_0} \sum_{t=t_0}^{\infty} \delta^{t-t_0} L_t$ is the expected discounted loss.

Woodford (2003) shows that the period loss in (4) represents a quadratic approximation to (the negative of) consumer welfare given that $\lambda = \psi^{-1}\gamma$ is a function of the elasticity of substitution between alternative differentiated goods (ψ) and elasticity of inflation with respect to output gap (γ). Thus minimizing the expected discounted loss produces the welfare maximizing equilibrium up to a quadratic approximation.⁶ Svensson (1997) denotes this monetary policy as flexible inflation targeting since the loss function includes arguments in addition to inflation. The central bank's instrument is the nominal interest rate at time $t + m$, since this is the relevant time period when the central bank can have an effect on output gap and hence on inflation (see equations (1) and (2)).

The Lagrangian associated with this problem is given by

$$\mathcal{L}_t = E_{t_0} \sum_{t=t_0}^{\infty} \delta^{t-t_0} \left[\frac{1}{2} (\pi_t^2 + \lambda x_t^2) - \mu_{t+j} (\pi_{t+j} - \delta \pi_{t+j+1} - \gamma x_{t+j} - \varepsilon_{t+j}) - \nu_{t+m} (x_{t+m} - x_{t+m+1} + \sigma (i_{t+m} - \pi_{t+m+1} - r_{t+m}^n)) \right]. \quad (5)$$

Note that the the objective function does not give any guidance as to how to set the level of the interest rate during the "pre-planning" period $[t_0, t_0 + m - 1]$. It only provides a criteria on how to set the optimal announcement of the interest rate m periods ahead. As noted by Svensson and Woodford (2005), however, the unforecastable component of the interest rate ($i_{t+m} - i_{t+m|t}$) influences neither of the target variables. Nor has the policymaker any incentives to deviate from the announcement and to produce surprises. Correspondingly, we assume that the policymaker sets the unforecastable part of interest rate to zero. The policymaker implements the interest rate policy therefore by setting $i_{t+m} = i_{t+m|t}$.

3.1. Discretion

Under the assumption that the central bank does not have access to commitment technology, the relevant policy regime is the one where the central bank optimizes its

⁶The welfare-theoretic loss function applies to the model with implementation lags, see Woodford (2003, ch. 8, p.570).

policy period by period. This situation is usually referred to as a discretionary policy regime. The policy problem under discretion can be solved analytically by finding the first-order conditions to the Lagrangian function (5) with respect to inflation, output and the interest rate at the horizon monetary policy can have an effect (the length of the implementation lags) on the economy, and by taking expectations as given. The first-order conditions are given by

$$\frac{\partial \mathcal{L}_t}{\partial \pi_{t+j}} = E_{t_0} \delta^{t-t_0} (\delta^j \pi_{t+j} - \mu_{t+j}) = 0, \quad (6)$$

$$\frac{\partial \mathcal{L}_t}{\partial x_{t+m}} = E_{t_0} \delta^{t-t_0} (\delta^m \lambda x_{t+m} - v_{t+m}) = 0, \text{ for } j > m, \quad (7)$$

$$\frac{\partial \mathcal{L}_t}{\partial x_{t+m}} = E_{t_0} \delta^{t-t_0} (\delta^m \lambda x_{t+m} + \gamma \mu_{t+m} - v_{t+m}) = 0, \text{ for } j = m, \text{ and} \quad (8)$$

$$\frac{\partial \mathcal{L}_t}{\partial i_{t+m}} = E_{t_0} \delta^{t-t_0} (-\sigma \delta^m v_{t+m}) = 0. \quad (9)$$

Assuming that $\lambda > 0$ (and that $j \geq m$), the first-order conditions (6)-(9) imply that for every period $t \geq t_0$,

$$\begin{aligned} x_{t+m|t} &= 0, \text{ for } j > m, \text{ and} \\ x_{t+m|t} &= -\frac{\gamma}{\lambda} \pi_{t+m|t}, \text{ for } j = m. \end{aligned} \quad (10)$$

Equations (1) and (10) determine the path for inflation and (expected) output gap. The policy rule for the future interest rate can be derived using equations (2) and (10):

$$\begin{aligned} i_{t+m|t} &= \pi_{t+m+1|t} + r_{t+m|t}^n, \text{ for } j > m, \text{ and} \\ i_{t+m|t} &= \left(1 + \frac{\gamma}{\sigma \lambda}\right) \pi_{t+m|t} - \frac{\gamma}{\sigma \lambda} \pi_{t+m+1|t} + r_{t+m|t}^n, \text{ for } j = m. \end{aligned} \quad (11)$$

Note that if $j \geq m \geq 1$, the output gap and inflation are both predetermined from the perspective of the policymaker for the "pre-planning" period of $[t_0, t_0 + m - 1]$ and $[t_0, t_0 + j - 1]$ respectively. In the pre-planning period, output and inflation are entirely determined by the cost-push and natural rate shocks respectively and not by the central bank's decisions at time t . Equations in (11) determine the optimal policy "announcements" m period in advance of policy implementation.

The optimality conditions in (10) show that the optimal monetary policy in the discretionary equilibrium depends on the relative length of the implementation lags. When inflation is predetermined for a longer time than output gap ($j > m$), the interest rate is set with the intention of keeping the real interest rate equal to its natural rate at the relevant policy horizon. The reason for this is that at the time policy is being announced, inflation is predetermined, and the central bank has no incentives to pay attention to inflation determination within the period. The policymaker does not trade off any output gap variability with inflation variability and there are no stabilization of cost-push shocks. Hence, it is optimal to fully stabilise the output gap. In the case with implementation lags of equal length ($j = m$), however, the central bank influences output gap and inflation in the same period. Thus the monetary authority trades off inflation expectations with output gap expectations without having to commit to future policies.

3.2. Commitment

If the central bank is able to commit, the solution to the problem is found by finding the first order conditions the same way as under discretion, but also taking into account of the effects of policy on expectations.

The first-order conditions are then

$$\frac{\partial \mathcal{L}_t}{\partial \pi_{t+j}} = E_{t_0} \delta^{t-t_0} (\delta^j \pi_{t+j} - \mu_{t+j} + \mu_{t+j-1} + \nu_{t+j-1} \sigma \delta^{j-m-1}) = 0, \quad (12)$$

$$\frac{\partial \mathcal{L}_t}{\partial x_{t+m}} = E_{t_0} \delta^{t-t_0} (\delta^m \lambda x_{t+m} - \gamma \mu_{t+m} \delta^{m-j} - \nu_{t+m} + \nu_{t+m-1} \delta^{-1}) = 0,$$

$$\frac{\partial \mathcal{L}_t}{\partial i_{t+m}} = E_{t_0} \delta^{t-t_0} (-\nu_{t+m} \sigma) = 0, \quad (13)$$

where the initial Lagrange multipliers are $\mu_{t_0+u-1} = \nu_{t_0+n-1} = 0$ for $u \in [0, \dots, j]$ and $n \in [0, \dots, m]$. These conditions imply that for $\lambda > 0$, the optimal plan will be given by

$$x_{t|t_0} = 0, \text{ for } t \in [t_0 + m, t_0 + j - 1] \text{ and } j > m, \quad (14)$$

$$x_{t|t_0} = -\frac{\gamma}{\lambda} \pi_{t|t_0}, \text{ for } t = t_0 + j, \quad (15)$$

and

$$\Delta x_{t|t_0} = -\frac{\gamma}{\lambda} \pi_{t|t_0}, \text{ for } t > t_0 + j. \quad (16)$$

The reason why the plan implies stabilizing the output gap perfectly for the first periods within the planning horizon, is that inflation is predetermined over this period and the central bank plan for the output gap does not influence the pricing decisions. The best solution is then to perfectly stabilize the output gap during the periods when inflation is pre-determined. This is clearly seen in Figures ?? and ?? that show the equilibrium responses of inflation and output to cost push shocks in the model with one period implementation lag in pricing and no implementation lag in output: under commitment, output gap is perfectly stabilised in the first period and with no reaction of the output gap to cost push shock.

Note that in if $j \geq m \geq 1$, the output gap and inflation are both predetermined as in the discretionary case above.

3.3. The effects of implementation lag

Before turning into comparing different policy regimes and discussing potential remedies for the discretionary policy, it is useful to look more closely to the effect of implementation lags on inflation and output gap and how the cost-push shock influences these variables in the optimal discretionary equilibrium.

We focus on the special case where inflation reacts to changes in monetary policy with one period greater lag than output gap such that $j = 1$ and $m = 0$. We contrast this to the case without implementation lags ($j = m = 0$). In the case with implementation lags, the solution for the output gap under discretion is given from equation (10) as

$x_t = 0$. The first-order difference equation for inflation can then be found by using (10) in equation (1). This results in

$$\pi_{t+1} = \delta\pi_{t+2|t} + \varepsilon_{t+1} \text{ for } j = 1, \text{ and} \quad (17)$$

$$\pi_t = \delta \left(\frac{\lambda}{\lambda + \gamma^2} \right) \pi_{t+1|t} + \left(\frac{\lambda}{\lambda + \gamma^2} \right) \varepsilon_t \text{ for } j = 0. \quad (18)$$

Under the assumption that the cost-push shock follows AR(1) process,

$$\varepsilon_{t+1} = \rho_\varepsilon \varepsilon_t + \hat{\varepsilon}_{t+1}, \quad (19)$$

the forward solution for inflation can be found by using the fact that $\pi_{t+1} = \pi_{t+1|t} + \varepsilon_{t+1} - \varepsilon_{t+1|t}$ and solving forward for $\pi_{t+1|t}$. This yields

$$\begin{aligned} \pi_{t+1} &= \varepsilon_{t+1} - \varepsilon_{t+1|t} + \sum_{i=0}^{\infty} \delta^i \varepsilon_{t+i+1|t} \\ &= \hat{\varepsilon}_{t+1} + \frac{\rho_\varepsilon}{1 - \delta\rho_\varepsilon} \varepsilon_t, \end{aligned} \quad (20)$$

where $\hat{\varepsilon}_{t+1} \equiv \varepsilon_{t+1} - \varepsilon_{t+1|t}$.

In the standard case where $j = m = 0$, the solution for output gap under discretion is given by equations (1), (10) and (19) yielding

$$x_t = -\frac{\gamma}{\gamma^2 + \lambda(1 - \delta\rho_\varepsilon)} \varepsilon_t. \quad (21)$$

The forward solution for inflation is found by combining equations (1) and (21), and equation with AR(1) specification of cost-push shock yielding

$$\begin{aligned} \pi_{t+1} &= \sum_{i=0}^{\infty} \frac{\lambda}{\lambda + \gamma^2} \left(\frac{\delta\lambda}{\lambda + \gamma^2} \right)^i \varepsilon_{t+i+1|t+1}, \\ &= \sum_{i=0}^{\infty} \frac{\lambda}{\lambda + \gamma^2} \left(\frac{\delta\lambda\rho_\varepsilon}{\lambda + \gamma^2} \right)^i \varepsilon_{t+1}, \\ &= \frac{\lambda}{\gamma^2 + \lambda(1 - \delta\rho_\varepsilon)} \varepsilon_{t+1} \\ &= \frac{1}{1 - \delta\rho_\varepsilon} \varepsilon_{t+1} - \frac{1}{1 - \delta\rho_\varepsilon} \left(\frac{1}{1 + \frac{\lambda}{\gamma^2}(1 - \delta\rho_\varepsilon)} \right) \varepsilon_{t+1} \\ &= \hat{\varepsilon}_{t+1} + \frac{\rho_\varepsilon}{1 - \delta\rho_\varepsilon} \varepsilon_t + \\ &\quad \frac{\delta\rho_\varepsilon}{1 - \delta\rho_\varepsilon} \hat{\varepsilon}_{t+1} - \frac{1}{1 - \delta\rho_\varepsilon} \left(\frac{1}{1 + \frac{\lambda}{\gamma^2}(1 - \delta\rho_\varepsilon)} \right) \varepsilon_{t+1}, \end{aligned} \quad (22)$$

The equilibrium behavior of the models with and without the implementation lag differ in two important respects. The first difference is related to the expectations channel. In the model with the implementation lag, the only immediate effect is a one-to-one

reaction of inflation to the surprise component of the cost-push shock $\hat{\varepsilon}_{t+1}$, ref. the first term in equation (20). Thus, inflation does not respond immediately to the expected future effect of the surprise as it does in the model without implementation lags (see equation (22)). In the model with implementation lags, the remaining effect is delayed by one period, ref. the second term in (20). However, only a part ρ_ε of the surprise shock survives until the second period and then affects the inflation path through the expectations channel as firms reoptimize prices given new information about the future path of marginal costs. This delayed effect reduces inflation variability in the model with implementation lag. The reduction is particularly large when the cost-push shocks have a little persistence, i.e. ρ_ε is small. The expectation channel is then relatively unimportant for inflation determination.

The second type of difference regards optimal policy under the two models. As noted above, the monetary policymaker does not respond by adjusting output gap in the case with the implementation lag and hence inflation is not insulated from the cost-push shock. In the absence of implementation lag, the monetary policymaker is able to trade off some of the inflation variability with output gap variability in response to the cost-push shock.

The monetary policy channel has a stronger impact on inflation if the persistence of the cost-push shock (ρ_ε) is large. If cost-push shocks are persistent and monetary policymaker does not stabilize the cost-push shock, the price setters expect marginal costs to be high for a long time. Hence, they increase today's prices at a faster rate and current inflation reacts strongly to the cost-push shock.

The effects on inflation are summarized by equation (23). It shows that inflation is a function of four terms in the model without implementation lags. The first two terms correspond to inflation in the model with the implementation lag. The third term represents the additional effect on inflation through the expectation channel and the fourth term represents the effect of a policy that insulates inflation from the cost-push shock.

4. Potential solutions to the credibility problem

The credibility problem of monetary policy can be alleviated by delegating monetary policy to a central bank with a modified loss function. Svensson and Woodford (2005) show that if the implementation lags of inflation and output gap both are equal to one, including the revision of the (one period ahead) inflation forecast in the social loss function with a weight corresponding to the loss caused by a marginal increase in the inflation forecasts (in optimum), produces a solution that replicates the timeless commitment solution. Although we do not argue against the possibility that there may be a modified extension to the loss function that can reduce the discretionary bias in the case of differing implementation lags too, the extension would however be highly model dependent. Furthermore, as Svensson and Woodford (2005) also note, such a solution to the discretionary problem involves “a somewhat abstract consideration for the purposes of practical policymaking”. Since we view implementability of the solution as essential, we do not explore this venue any further and restrict the analysis by only considering regimes that seem realistic alternatives to flexible inflation targeting.

The benefits of price-level targeting versus inflation targeting have been discussed by Vestin (2006). He shows that price-level targeting under discretion can produce an outcome that replicates inflation targeting under commitment. Price level targeting may

in many respects represent an improvement over inflation targeting, not only because it reduces the credibility problem of the central bank, but also because it is easily implementable and it is indeed a practical alternative to inflation targeting. It does not, however, in its flexible form alleviate the credibility problems caused by implementation lags for the same reason as above: prices are predetermined at the horizon the policymaker can affect the output gap.

4.1. Strict targeting regimes

A standard argument favouring strict targeting regimes is that they alleviate the credibility problems since the concentration is on only one objective. This removes the temptation to deviate from the commitment to the main target variable. There are essentially only three candidate solutions for a strict targeting regime: inflation, price-level or money growth targeting. The period loss functions are given respectively by

$$\begin{aligned} L_t &= \pi_t^2, \\ L_t &= p_t^2, \text{ and} \\ L_t &= \Delta m_t^2 \end{aligned}$$

for these targeting regimes. In what follows, we discuss the properties of these regimes under implementation lag in pricing.

4.1.1. Strict inflation and price-level targeting

For the particular case of strict inflation targeting (where $\lambda = 0$), the first order conditions in equations (6) to (9) imply that for every period $t \geq t_0$,

$$\pi_{t+j|t} = 0. \quad (24)$$

The solution for output gap is given by combining this optimality condition with equation (1) to have

$$x_{t+j|t} = -\frac{1}{\gamma} \varepsilon_{t+j|t}. \quad (25)$$

Comparing this solution to the one under flexible inflation targeting, obtained in equation (10), there is a discontinuity in the monetary policy strategy at $\lambda = 0$ whenever $j > m$. Under strict inflation targeting, the central bank achieves perfect stability of inflation expectations at horizon j whereas for any small positive value of λ , only the output gap is stabilized at horizon m since the occurrence of the output gap in the loss function introduces a temptation for the central bank to deviate from the inflation forecast target.

A similar argument goes for strict price-level targeting. The first-order conditions imply that for $t \geq t_0$,

$$p_{t+j|t} = 0. \quad (26)$$

The solution for output gap is again given by combining this optimality condition with equation (1) to have

$$x_{t+j|t} = -\frac{1}{\gamma} (\varepsilon_{t+j|t} + p_{t+j-1|t}). \quad (27)$$

The solution strategy allows to determine forecast of the output gap at horizon $t + j$ and after for both inflation and price-level targeting, but it does not allow to determine, in the case of $j > m$, output gap for horizon m to $j - 1$. Over this horizon, the central bank does have an effect on inflation and output gap, but the target criterion does not give any guidance how to set the interest rate. In particular, the targeting criterion is silent on how to respond to new information that impacts present period output gap.

In order to come up with a way of determining the output gap for horizon m to $j - 1$, we need specify how the monetary policymaker responds to the part of the new information that is irrelevant from the perspective of the j -period ahead forecast but relevant for the periods before in which policy has an influence on output. There are many potential solutions to this problem as the CB in principle could respond in an infinite number of ways. One solution stands out, however. This solution implies that the central bank responds to the part of the new information by stabilizing output at the horizon $[m, j - 1]$. This is the solution that would maximize welfare under strict targeting. We denote these targeting regimes as "augmented strict targeting" under implementation lag in pricing. It could however be argued that such an augmented regime constitutes a contradicting of itself: it implicitly assumes preferences over output. In which case it is considered a flexible inflation targeting regime and its solution should apply. We nevertheless present the result from the simulation of such a regime below.⁷

4.1.2. Money growth targeting

Money growth targeting was originally promoted by Friedman (1960) partly due to the perceived problems associated with transmission lags. Friedman warned against trying to stabilize prices and inflation directly in a discretionary manner due to long and variable lags in the transmission mechanism of monetary policy.

[...] the link between price changes and monetary changes over short periods is too loose and too imperfectly known to make price level stability an objective and reasonably unambiguous guide to policy. [...] [T]here is much evidence that monetary changes have their effect only after a considerable lag and over a long period and that the lag is rather variable. (p. 87)

He instead promoted the well-known $k - \%$ money growth rule:

[T]he stock of money [should] be increased at a fixed rate year-in and year-out without any variation in the rate of increase to meet cyclical needs. (p. 90)

Friedman argued that discretionary policymaking aiming to stabilize inflation could potentially be destabilizing due to imperfect knowledge about the transmission mechanism of monetary policy, including its lag structure. Although imperfect knowledge is not the reason why transmission lags of monetary policy creates credibility problems

⁷Knowing that commitment and discretion coincide for strict price-level and inflation targeting, we derive the "augmented strict targeting" regimes under commitment with a full weight either on inflation or prices and a very small weight on the output gap. The weight on output gap has a negligible effect on the inflation and price-level forecasts, but is directive of the (short-run) output forecasts.

analysed in his paper, the money growth targeting strategy does offer some robustness to different lag specifications since its strategy will be independent of the lag structure of the economy.⁸ Furthermore, and as noted above, money growth targeting (or the "Friedman's $k - \%$ rule") does not involve the potential temptation to deviate from the announced policy as is the case under the welfare optimizing regime (flexible inflation targeting). Importantly, Söderström (2005) discusses the benefits of money growth targeting in the New Keynesian framework as a solution to the credibility problem. For these reasons, we investigate how transmission lags influences money growth targeting as a solution to the credibility problem.

In order to derive the interest rate implications of money growth targeting, we assume that the demand for money is given by a conventional money demand function⁹

$$m_t - p_t = x_t - \kappa i_t + v_t. \quad (28)$$

By subtracting real money balances $\hat{n}_{t-1} \equiv m_{t-1} - p_{t-1}$ from both sides, the growth rate of money supply is given by

$$\Delta m_t = \pi_t + \Delta x_t - \kappa i_t - \hat{m}_{t-1} + v_t. \quad (29)$$

Under money growth targeting, the central bank chooses $\Delta m_t = 0$. The interest rate then follows from (29) and is given by

$$i_t = \frac{1}{\kappa} [\pi_t + \Delta x_t - \hat{m}_{t-1} + v_t]. \quad (30)$$

As noted above, we see that the interest rate under money growth targeting rule is independent of the length of the transmission lags.

5. Welfare and the discretionary bias

In this section we study the effects on social loss of implementation lags in pricing decisions and compare it to the standard model with no implementation lag.

We let the disturbances to the output gap and money demand equations follow the AR(1) processes such that

$$r_{t+1}^n = \rho_r r_t^n + \hat{r}_{t+1}^n, \quad (31)$$

$$v_{t+1} = \rho_v v_t + \hat{v}_{t+1}. \quad (32)$$

As noted above, ε_t is a cost-push shock, r_t^n is a shock to the natural rate of interest and v_t is a money demand shock. We calibrate the model according to Giannoni and Woodford (2005) by setting $\beta = 0.99$, $\gamma = 0.024$, $\sigma = 0.16$, $\rho_r = 0.35$, and $\sigma_{\hat{r}} = 0.0372$. Since Giannoni and Woodford (2005) do not produce calibrated values for the parameters in the cost-push shock process, we set $\sigma_\varepsilon = 0.01$ and $\rho_\varepsilon = 0.5$ in the standard calibration

⁸In Kilponen and Leitimo (2008) we discuss the advantages of money growth targeting in providing robustness against model uncertainty when there are implementation lags in price setting.

⁹See for instance Walsh (2003), ch. 2 for the derivation of money demand equation in the context of dynamic money-in-the-utility function model.

of the model. We also consider other degrees of persistence of the cost push shock ρ_ε in the model below. For the parameters in the money demand equation (28), we have used the estimates from Kilponen and Leitemo (2008). Using the US data¹⁰ over the period 1980q1 – 2004q4, we obtained an estimate of $\kappa = 0.43$ with a coefficient standard error of 0.11.¹¹ Moreover, the estimated parameter values of the disturbance processes are $\rho_v = 0.77$ and $\sigma_{\hat{v}} = 0.0116$. Finally, the elasticity of substitution between alternative differentiated goods (ψ) is parameterized as $\psi^{-1} = 0.13$ as in Woodford (2003). This implies that inflation is the component of the welfare loss that dominates, and social loss can be studied primarily by the impact on inflation.

5.1. Maximizing consumer welfare

We compute the welfare loss under the discretionary and commitment equilibria. Furthermore, we illustrate the importance of the persistence of cost push shocks by analyzing the two models with two alternative assumptions about the persistence of cost push shock. Results as regards welfare losses are presented in Table 1. Figures 1-5 in appendix B show the equilibrium responses of the models under different policies and assumptions about the persistence of cost-push shocks.

For our baseline specification of welfare ($\lambda = \psi^{-1}\gamma$) and persistence of the cost-push shocks of ($\rho_\varepsilon = 0.5$), there are substantial benefits in having access to commitment technology if the central bank is maximizing welfare directly through inflation targeting. The welfare loss is 73 per cent higher with discretion in the standard model. The gains from committing are slightly lower under the model with the implementation lag - the loss is now 52 per cent higher than under commitment. Commitment is more important in the setting without implementation lag since the expectations channel has a stronger influence on the outcome, as discussed previously. The relative loss of discretion increases with a higher degree of persistence in the cost-push shock ($\rho_\varepsilon = 0.7$). Discretion produces welfare losses that is 123 per cent and 258 per cent higher than under commitment in the model with and without the implementation lag respectively. The presence of an implementation lag now worsens the discretionary equilibrium substantially. Since the shock is expected to have a more persistent effect on costs, the control of expectations channel via the appropriate design of monetary policy is vital to the outcome. Such a control is not available to the policymaker in the discretionary equilibrium.

As noted in the previous section, the persistence of the cost-push shock influences whether or not lags in the model improve on the relative performance of the discretionary policy. With the baseline assumption of $\rho_\varepsilon = 0.5$, a lag will in fact improve on the relative performance of discretion. This is a result of firms not accounting for the future effect of the shock in the period in which the shock occurs which has a moderating effect on inflation, and thus on welfare loss. This effect outweighs the effect of a missing monetary policy channel on inflation. However, this result is overturned if the cost-push shock becomes sufficiently persistent ($\rho_\varepsilon = 0.7$).

¹⁰The estimation was carried out with ordinary least square allowing for serial correlation of the residual of order one. We used HP-filtered data on log monetary base, log GDP deflator, log GDP and the federal funds rate. The detrending was carried out with a smoothing parameter of 1600 over the period 1960q1-2005q4.

¹¹Varying the endpoint of the estimation period between 1990q1 and 2005q4, produced estimates between 0.35 and 0.45 for κ , well within the 90% confidence interval of the estimate in the shorter period. The estimated value for κ stabilized very close to our point estimate after year 2000.

The central bank can improve significantly on the outcome with money growth targeting. This is in particular evident in the model with the implementation lag, where loss is only 12 per cent above the optimal commitment equilibrium as opposed to 52 per cent in the model without lags. The model supports the claim by Friedman that money growth targeting is welfare improving in particular if there are transmission lags in monetary policy, but for a different reason: Money growth targeting alleviates the problem caused by a lack of credibility with discretionary inflation-targeting policy.

Although the performance of money growth targeting deteriorates relative to the optimal commitment policy with increased cost-push persistence ($\rho_\varepsilon = 0.7$), it improves relative to the discretionary inflation targeting equilibrium. With increased persistence and the implementation lag, money growth targeting reduces the loss (relative to inflation targeting under discretion) by 61 percent compared to 28 percent in the case with baseline persistence. The corresponding numbers are 21 percent and 12 percent in the model without the implementation lag.

The benefits of money growth targeting is due to its ability to induce history dependence in policymaking. As can be seen from the implied interest rate rule in (30), money growth targeting features history dependence through the terms Δx_t and \hat{m}_{t-1} .¹² Such a history dependent policy affects people's expectations about the future. This can improve the equilibrium substantially in a model where these expectations play a major role. Figures 1-4 in appendix A.2 show the equilibrium responses of the model to a cost-push shock. The response under money growth targeting bears relatively close resemblance to that of the optimal commitment policy. It produces hump-shaped output gap and inflation responses that reflect the history-dependence of the policy under both the commitment and money growth rule. Why does history dependence contribute to an improved outcome? Under both money growth targeting and the commitment equilibrium, the price level is (trend) stationary. Under money growth targeting prices will over time return to the money growth path. A cost-push shock that raises inflation today will lead to people expecting future inflation to be relatively low as to get prices in line with money. Lower long term expectations of inflation has a moderating effect on current short term inflation expectations and this has a stabilizing effect on inflation process.

Money growth targeting does not exactly replicate the commitment solution, however, and is furthermore inefficiently affected by money demand shocks¹³ that induce variability in the interest rate. The variability in the interest rate induces inefficient movements in output gap which in turn affects inflation. In the case with implementation lags on prices, however, the initial shock to money demand has no impact on inflation since prices are predetermined. This reduces the inefficient impact of the money demand shock since only a part of the money demand shock survives into the future and can affect inflation. This is the reason why the efficiency of money growth targeting increases with the implementation lag.

Neither strict inflation nor price-level targeting do particularly well in either of the specifications. The reason is that output gets very volatile (see also Figure 5 in appendix B) and despite a small weight on output stability in the welfare specification, this has

¹²This is extensively discussed in Söderström (2005).

¹³The instability of money demand may be particularly severe in states of financial crises or when the economic is hovering above a deflationary or liquidity trap.

a strong effect on welfare. Strict price-level targeting is worse than direct optimization of welfare under discretion in all four model specifications. In particular, it does badly in the case with an implementation lag. The reason is that the central bank is not able to stabilize inflation perfectly due to the implementation lag. The central bank needs to reverse any effects of the price level due to shocks during the implementation period by creating either negative or positive inflation. This implies strong volatility in inflation. The beneficial effect on inflation expectations caused by price-level targeting as noted by Vestin (2006) are not sufficient to outweigh these other effects.

Strict inflation targeting does somewhat better. Indeed, it improves on the discretionary welfare maximizing policy when there is an implementation lag and persistence in the cost-push shock is sufficiently high. The equilibrium produces about twice the loss of the commitment equilibrium. A robustness check with both higher ($\rho_\varepsilon = 0.9$) and lower ($\rho_\varepsilon = 0.3$) cost-push shock persistence (but keeping the variance constant) reported in 3, suggests that strict inflation targeting may do quite well and even improve on monetary growth targeting if persistence is sufficiently high. This is also true for price-level targeting in a model without the implementation lag. For the other regimes, the analysis suggests that the qualitative conclusions remain intact.

5.2. *Alternative welfare specification*

Although the above welfare criterion reflects consumer welfare in the model, it could be argued that policy values output gap stability too little. Central banks seem to value output gap stability more than above, as the output gap is empirically more stable than policies based on the above criterion would suggest. In the analysis below, we have set $\lambda = 0.5$, implying that society values inflation stability only twice as important as output gap stability.

Valuing a more stable output gap changes the results in important ways (see Table 2). First of all, the discretionary welfare maximizing policy does much better than before. For the standard model, the inefficiencies of discretionary policy of stabilizing inflation is relatively less important now since the relative weight on inflation in welfare is smaller. For the model with an implementation lag, the policy of making output completely stable is more valued and therefore the difference to the commitment equilibrium is smaller.

The performance of the money growth targeting regime is now far worse since much more emphasis is put on the regime's ability to stabilize output. The money growth targeting regimes is no longer a good remedy for the credibility problems associated with the model, neither with or without the implementation lag. Neither is a remedy needed as much since the discretionary equilibrium is much closer to the commitment equilibrium. The strict inflation and price-level targeting regimes are now disastrous since they imply far too much output gap variability in comparison to society's desire. An identical robustness check over different degrees of persistence as above is reported in Table 4.

6. Conclusions

It is well established that monetary policy is subject to transmission lags. These lags can be the results of delayed responses of the private sector to economic shocks. We show under the reasonable assumption that when inflation reacts with a longer lag than

output gap to changes in monetary policy, the optimal discretionary equilibrium implies no policy-induced stabilization of cost-push shocks. Since inflation is predetermined at the time when monetary policy can influence output gap, the discretionary optimizing policymaker stabilize the output gap perfectly and does not stabilize inflation. This result can be generalized as to having policy only stabilizing the target variable with the shortest transmission lag.

For standard specification of welfare we find that implementation lags in prices increase the discretionary stabilization bias severely if cost-push shocks are sufficiently persistent. Money growth targeting reduces the bias substantially, since it features history dependence, similarly to the policy under commitment equilibrium. For the alternative specification of welfare that values output far more, however, the discretionary bias is substantially smaller and money growth targeting does not offer a remedy for reducing the discretionary bias. In fact it does substantially worse.

For either specifications, strict targeting of inflation or the price-level does not produce a good outcome. If there are implementation lags, strict price-level targeting seems to be particularly detrimental to the economy.

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Appendix A. The state space representation

The model is solved using standard numerical solution methods (Svensson and Woodford (2003)) for rational expectations models. These solutions methods require the setting up of the model in state space form. For the standard case with no implementation lags, the state space form is relatively straight forward and is not shown here. For the case with implementation lags, the state space is more complicated. Here we show the state space form with a one-period implementation lags for prices ($j = 1, m = 0$). The state space takes the form

$$A_0 Z_{t+1} = AZ_t + Bi_t + C\Sigma_{t+1}$$

where

$$\begin{aligned} Z_t &= [p_{t-1} \quad i_{t-1} \quad v_t \quad r_t^n \quad \varepsilon_t \quad \hat{m}_{t-1} \quad \pi_t \quad \pi_{t+1|t-1} \quad x_{t|t-1}]' \\ Z_{t+1} &= [p_t \quad i_t \quad v_{t+1} \quad r_{t+1}^n \quad \varepsilon_{t+1} \quad \hat{m}_t \quad \pi_{t+1} \quad \pi_{t+2|t} \quad x_{t+1|t}]', \\ \Sigma_{t+1} &= [\hat{v}_{t+1} \quad \hat{r}_{t+1}^n \quad \hat{\varepsilon}_{t+1}]', \end{aligned}$$

$$A_0 = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & \frac{\gamma}{\delta} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}, A_1 = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \rho_v & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \rho_r & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \rho_\varepsilon & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & \frac{-\rho_\varepsilon}{\delta} & 0 & 0 & \frac{1}{\delta} & 0 \\ 0 & 0 & 0 & -\sigma & 0 & 0 & 0 & -\sigma & 1 \end{bmatrix},$$

$$B = [0 \quad 1 \quad 0 \quad 0 \quad 0 \quad -\kappa \quad 0 \quad 0 \quad \sigma]'$$
 and

$$C = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 \end{bmatrix}'.$$

Appendix B. Equilibrium responses to cost push shocks in different policy regimes

[Figure 1 about here]

[Figure 2 about here]

[Figure 3 about here]

[Figure 4 about here]

[Figure 5 about here]

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Figure Legends

Fig 1: Equilibrium responses to one standard deviation cost-push shock ($\rho_\epsilon = 0.5$) – standard NK model without implementation lags.

Fig 2: Equilibrium responses to one standard deviation cost-push shock ($\rho_\epsilon = 0.7$) – standard NK model without implementation lags

Fig 3: Equilibrium responses to one standard deviation cost-push shocks ($\rho_\epsilon = 0.5$) – one period implementation lag in pricing.

Fig 4: Equilibrium responses to one standard deviation cost-push shocks ($\rho_\epsilon = 0.7$) – one period implementation lag in pricing.

Fig 5: Equilibrium responses to one standard deviation cost-push shocks with strict inflation and price level targeting – one period implementation lag in pricing.

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Tables

Table 1: Comparison of welfare losses under different models and policies

<i>Equilibrium</i>	$j = 0$	$j = 1$	$j = 0$	$j = 1$
	$\rho_\varepsilon = 0.5$		$\rho_\varepsilon = 0.7$	
Commitment	0.142	0.109	0.216	0.155
Discretion	0.246	0.170	0.481	0.555
	(73%)	(55%)	(123%)	(258%)
Money growth targeting	0.216	0.122	0.382	0.216
	(52%)	(12%)	(77%)	(39%)
Strict inflation targeting	0.534	0.207*	0.531	0.308*
	(276%)	(90%)	(146%)	(99%)
Strict price-level targeting	0.534	1.076*	0.531	1.008*
	(276%)	(887%)	(146%)	(550%)

Note: Table compares the losses in different policy regimes under baseline parameter specification of the model. Welfare losses are computed as in Svensson and Woodford (2003) and they are scaled up by a factor 10^3 . The numbers in parentheses refer to loss relative to the commitment equilibrium. (*) denotes an augmented strict targeting regime where the weight on the output gap is 10^{-10} .

Table 2: Comparison of welfare losses under different models and policies

Equilibrium	$j = 0$	$j = 1$	$j = 0$	$j = 1$
	$\rho_\varepsilon = 0.5$		$\rho_\varepsilon = 0.7$	
Commitment	0.356	0.162	0.890	0.482
Discretion	0.386	0.170	1.034	0.555
	(8%)	(5%)	(16%)	(15%)
Money growth targeting	1.356	0.955	3.78	2.63
	(280%)	(489%)	(325%)	(446%)
Strict inflation targeting	85.65	21.27*	85.12	41.3*
	(> 500%)	(> 500%)	(> 500%)	(> 500%)
Strict price-level targeting	85.65	148.95*	85.12	145.5*
	(> 500%)	(> 500%)	(> 500%)	(> 500%)

Note: Table compares the losses in different policy regimes when $\lambda = 0.5$. Welfare losses are computed as in Svensson and Woodford (2003) and they are scaled up by a factor 10^3 . The numbers in parentheses refer to loss relative to the commitment equilibrium. (*) denotes an augmented strict targeting regime where the weight on the output gap is 10^{-10} .

Table 3: Comparison of welfare losses under different models and policies -sensitivity analysis with respect to persistence of the cost push shocks

<i>Equilibrium</i>	$j = 0$	$j = 1$	$j = 0$	$j = 1$
	$\rho_\varepsilon = 0.3$		$\rho_\varepsilon = 0.9$	
Commitment	0.100	0.100	0.360	0.307
Discretion	0.148	0.108	1.305	6.427
	(48%)	(8%)	(263%)	(> 500%)
Money growth targeting	0.138	0.106	0.738	0.576
	(38%)	(6%)	(105%)	(88%)
Strict inflation targeting	0.536	0.138*	0.514	0.431*
	(436%)	(38%)	(43%)	(40%)
Strict price-level targeting	0.536	1.00*	0.514	0.732*
	(436%)	(> 500%)	(43%)	(138%)

Note: Table compares the losses in different policy regimes under alternative parameterisations of the cost push shock and under a small weight on output gap ($\lambda = \psi^{-1}\gamma$). Welfare losses are computed as in Svensson and Woodford (2003) and they are scaled up by a factor 10^3 . The numbers in parentheses refer to loss relative to the commitment equilibrium. (*) denotes an augmented strict targeting regime where the weight on the output gap is 10^{-10} .

Table 4: Comparison of welfare losses under different models and policies -sensitivity analysis with respect to persistence of the cost push shocks

<i>Equilibrium</i>	$j = 0$	$j = 1$	$j = 0$	$j = 1$
	$\rho_\varepsilon = 0.3$		$\rho_\varepsilon = 0.9$	
Commitment	0.190	0.107	5.08	4.09
Discretion	0.200 (5%)	0.108 (1%)	7.83 (54%)	6.43 (57%)
Money growth targeting	0.667 (251%)	0.577 (439%)	19.07 (275%)	16.20 (296%)
Strict inflation targeting	85.85 (> 500%)	7.74* (> 500%)	82.42 (> 500%)	66.11* (> 500%)
Strict price-level targeting	85.85 (> 500%)	131.7* (> 500%)	82.42 (> 500%)	111.39* (> 500%)

Note: Table compares the losses in different policy regimes under alternative parameterizations of the cost push shock and when $\lambda = 0.5$. Welfare losses are computed as in Svensson and Woodford (2003) and they are scaled up by a factor 10^3 . The numbers in parentheses refer to loss relative to the commitment equilibrium. (*) denotes an augmented strict targeting regime where the weight on the output gap is 10^{-10} .

Fig 1:

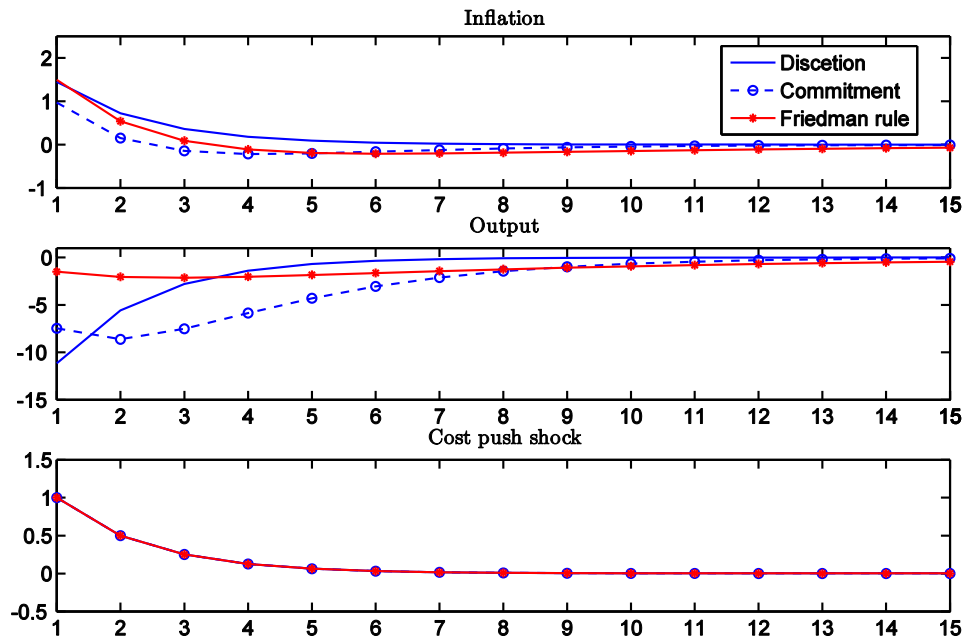


Fig 2:

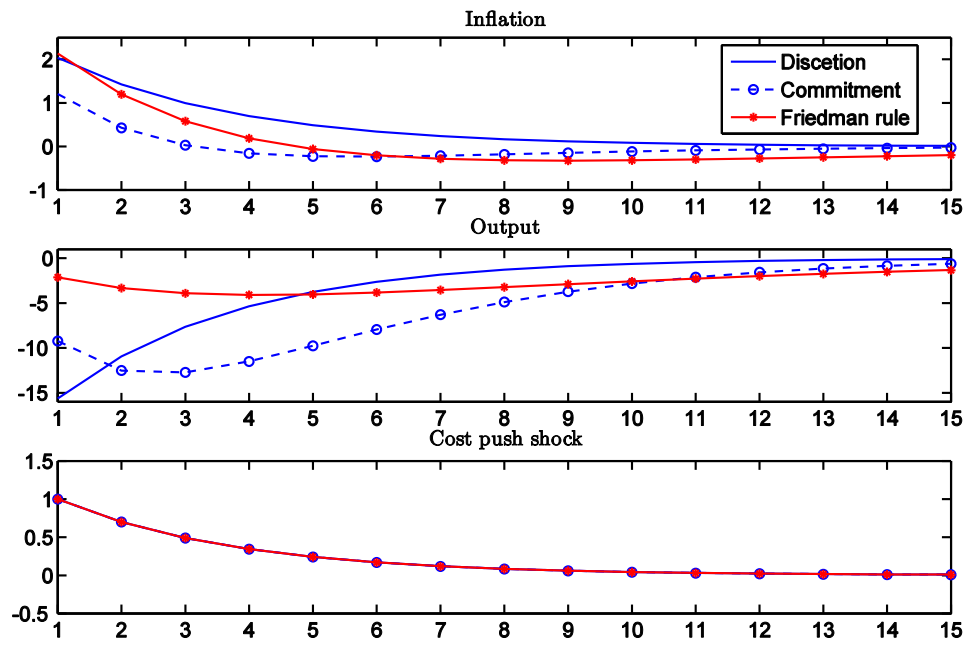


Fig 3:

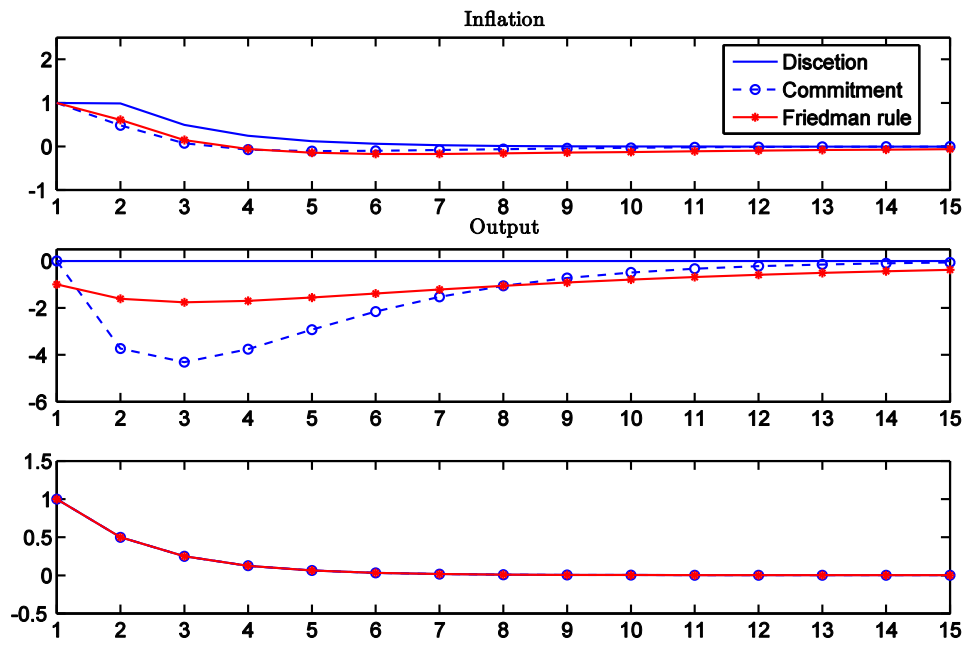


Fig 4:

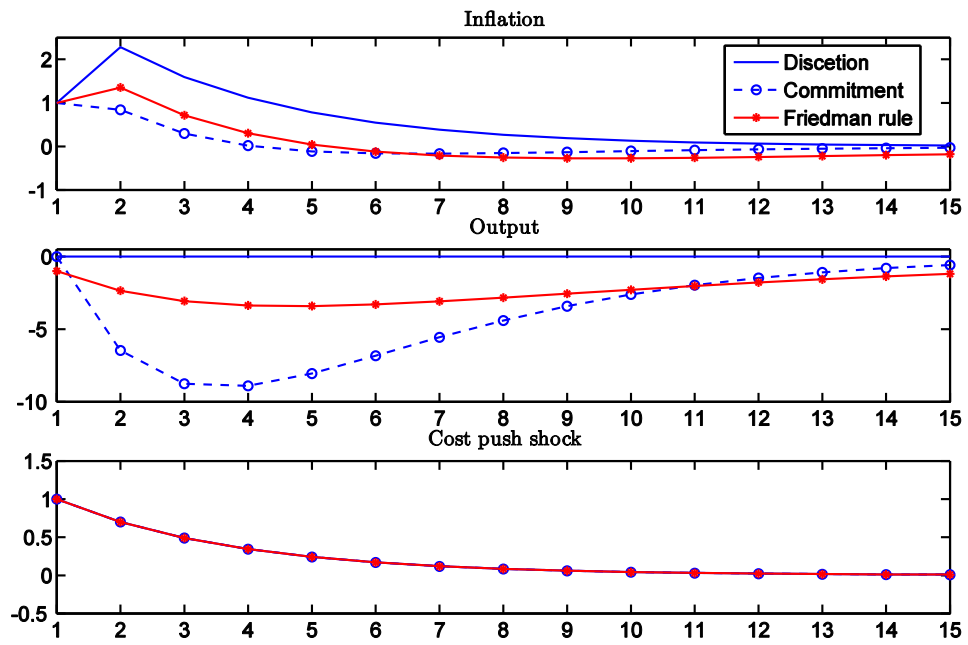


Fig 5:

