The Importance of Commitment in the New Keynesian Model

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Abstract

In the New Keynesian model, even if the central bank does not have an over-ambitious output target, policy under discretion leads to an inefficiency known as the stabilisation bias. In this paper, using a New Keynesian model, we explore and quantify how various uncertainties such as an information lag, a cost channel and multi-period data revisions affect the size of the stabilisation bias. When an information lag is introduced in an otherwise standard New Keynesian model, we find that the size of the stabilisation bias is considerably reduced. The presence of a cost-channel in the model, on the other hand, increases the stabilisation bias significantly. Finally, multi-period revisions to output and inflation, reduces the inefficiency associated with discretionary policy.

Keywords: stabilisation bias, discretion, commitment, cost-channel, information lags, data revisions

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1 Introduction

How important is commitment in the New Keynesian (NK) model? According to the recent literature on monetary policy, there are significant gains if a central bank can credibly anchor inflation expectations through a commitment to a low inflation target. Moreover, there are benefits from commitment even in the absence of an average inflation bias as policy under discretion in the NK model remains inefficient since it generates a stabilisation bias. Unlike the inflation bias that affects the steady-state level of inflation, the stabilisation bias is a dynamic inefficiency that influences the ability of policy-makers to stabilize inflation through time. This bias emerges because of insufficient inertia in the policy actions of the central bank and is typically characterized by an excessive stabilisation of output at the expense of inflation.

As discussed in Woodford (2003), when the behaviour of private agents is forward-looking, optimal monetary policy under commitment exhibits a considerable degree of inertia. The reason why an inertial policy is optimal is simple: if private agents believe that the central bank will keep the short-term interest rate above its neutral value, even long after the (cost-push) shock has passed, they will lower their expectations of future inflation. This shift in expectations will have a favourable impact on the current period inflation as expected future inflation is an important driver of current inflation in the NK model. This expectations channel is, however, absent under discretion since the central bank, by not making any promises on future actions, cannot affect the public's expectations about future inflation. As a result, the central bank, under discretion, faces a less favourable output-gap–inflation trade-off, resulting in a stabilisation bias.

Most studies on the stabilisation bias have focused on the importance of forward versus backward-looking inflation expectations. It is clear that the gains from commitment in the NK model are largely dependent on the forward-looking nature of inflation. This point is explicitly formulated in Clarida et al. (1999), Dennis and Söderström (2006) and some other studies. However, there are other factors, such as the persistence of the cost-push shock and the slope of the Phillips curve that affect the size of the stabilisation bias in the NK model. Dennis and Söderström (2006) and Tillman (2009) show that commitment becomes more important if the cost-push shock is more persistent and if the NK Phillips curve becomes flatter. This result is intuitive. In both cases, the central bank faces a less favourable output-gap inflation trade-off, resulting in a larger stabilisation bias and thus increasing the value of commitment.

Although the literature has extended the basic NK model in numerous directions to include features such as information lags, cost-channel, real rigidities and various forms of uncertainty, there are very few studies that have examined the implications of these extensions on the role of commitment and the size of the stabilisation bias. One notable exception is Dennis and Söderström (2006). They evaluate the importance of commitment in three empirical models of the NK type, notably the models of Fuhrer and Moore (1995), Orphanides and Wieland (1998) and Rudebusch (2002). These models feature backward and forward-looking expectations and lags in the transmission of monetary policy in the model of Rudebusch (2002). They find that the size of the stabilisation bias depends on the degree of forward and backward-looking expectations in the model as previously stressed by Clarida et al. (1999). Moreover, they also report that the importance of commitment is greatly reduced in models that feature a delayed response of monetary policy arising from a transmission and an information lag as in the model of Rudebusch (2002).

In this paper, we explore and quantify the importance of commitment and the size of the stabilisation bias by considering some of the recent extensions to the basic NK model. Our paper is thus related to Dennis and Söderström (2006) but differs in three important ways. First, all the models we employ are microfounded and nested. The models they utilize are to a large extent ad-hoc and non-nested. Second we modify the standard NK model, in turn, to include a lag in the information set, a cost channel and an observational uncertainty in the form of noisy information on output and inflation. Dennis and Söderström (2006) consider only models that include information as well as transmission lags. We choose these three extensions as they have been the subject of many recent studies in the NK literature and have been shown to be theoretically and empirically important.[2] Moreover, for each extension, we examine the size of the stabilisation bias for various degrees of inflation expectations and not just for completely forward-looking or backward-looking models. Third, we provide analytical results whenever possible and not just numerical simulations.

We find that the size of the stabilisation bias and thus the importance of commitment are greatly reduced when the model features a delayed response of monetary policy in the

[2]For example, see Ravenna and Walsh (2006) on the cost channel, Woodford (2003) on models with delayed effects of monetary policy and Gerali and Lippi (2003) and Ehrmann and Smets (2003) on measurement errors.

form of an information lag. Even when inflation expectations are very forward-looking, the gains from commitment are very small. This finding is similar to the result Dennis and Söderström (2006) found using the Rudebusch (2002) model, albeit in a model where inflation expectations are not completely forward-looking. When we introduce a cost channel, we find a substantial increase in the size of the stabilisation bias. Moreover, in this model, we find that the stabilisation bias remains fairly large even when inflation expectations are completely backward-looking. This result holds as long as consumers are optimizers in the model. In the model with observational uncertainty in the form of measurement errors on output and inflation, we find that the gains from commitment are smaller compared to the baseline model. The size of the stabilisation bias decreases as the size of the revisions to output and inflation increases. The paper is organized as follows. In section 2, we describe the different NK models. Section 3 characterizes optimal policy in each model. Section 4 presents our numerical results and section 5 concludes.

2 Model

The model consists of a continuum of identical households with an infinite planning horizon, a monetary authority that either commits to a policy or operates under discretion, monopolistic competitive firms, sluggish price adjustment, rule of thumb price setters and optimizing consumers. We assume this asymmetry in the model purely because the presence of rule of thumb consumers is not an important determinant of the size of the stabilisation bias and can thus be ignored. On the other hand, the existence of rule of thumb price setters will give rise to a NK Phillips curve that has backward and forward-looking inflation expectations. The importance of commitment, as we will see, will depend to a large extent on the degree of forward versus backward-looking expectations about inflation in the model.[3]

The model differs from the standard New Keynesian model as we assume that expenditure decisions may be predetermined. Moreover, we have a binary parameter in the model that determines whether there is a cost channel or not. Apart from these features, our model is a stylized New Keynesian framework that has been extensively studied (see Walsh (2003) for example). We first present the micro-foundations of our nested models and subsequently

[3] We have performed numerical simulations with a version of the model that also features rule of thumb consumers. Our results do not depend on the rule of thumb consumers but depend on the rule of thumb producers. For this reason, we have this asymmetry in the model.

discuss the different versions we utilize. Since the features of our model follow closely those of Amato and Laubach (2003) and Ravenna and Walsh (2006), we only provide an overview of its derivations.

Households maximize the expected present discounted value of utility given by:

$$E_{t-d}\sum_{j=0}^{\infty}\beta^{j}\left\{\xi_{t+j}\frac{C_{t+j}^{1-\sigma}}{1-\sigma}-\frac{N_{t+j}^{1+\varphi}}{1+\varphi}\right\} \tag{1}$$

where $\beta \in (0,1)$ denotes the discount factor, C_t a consumption basket, N_t hours worked from which the agent derives disutility, σ^{-1} the intertemporal elasticity of substitution, φ^{-1} the labour supply elasticity and ξ_t is a preference shock. The main difference between this model and the basic New Keynesian model is that expectations may be conditional on information up to an including t-d and not t, reflecting the fact that expenditure decisions are predetermined. In the basic New Keynesian model, $d = 0$, whereas in the model with an information lag where expenditures are predetermined, we set $d = 1$. Aggregate consumption in this economy is given by the standard Dixit-Stiglitz aggregate:

$$C_t = \left(\int_0^1 C_{it}^{\frac{\alpha-1}{\alpha}}\,di\right)^{\frac{\alpha}{\alpha-1}} \tag{2}$$

where i indexes differentiated goods and α denotes the elasticity of substitution among the different goods. The associated aggregate price index is given by:

$$P_t = \left(\int_0^1 P_{it}^{1-\alpha}di\right)^{\frac{1}{1-\alpha}} \tag{3}$$

Finally, the demand function for each variety of good is:

$$C_{it} = \left(\frac{P_{it}}{P_t}\right)^{-\alpha} C_t \tag{4}$$

Households face a cash in advance constraint in this model. They enter each period with an amount of cash M_t and they also receive their wage income N_tW_t at that time, where W_t denotes the nominal wage rate. They use their resources to purchase goods P_tC_t and use the remaining cash to make a deposit D_t at the financial intermediary. This deposit earns a gross nominal interest R_t. The financial intermediary in the model uses the deposits and an exogenous cash injection to finance the borrowing needs of firms. Nominal consumption is assumed to be fully financed with cash. The cash-in advance constraint is given by:

$$P_tC_t \leq W_tN_t + M_t - D_t \tag{5}$$

Households are assumed to own the firms and financial intermediaries and money flows back to the households in the form of dividend and/or profit payments. Thus the nominal income of households is composed of wage income W_tN_t, interest income earned on deposits R_tD_t, profits earned from financial intermediaries and firms, F_t. A typical household expenditure consists of consumption and money balances that are carried forward to the next period. Thus the household budget constraint is given by:

$$M_{t+1} = M_t + W_tN_t + R_tD_t + F_t - P_tC_t - D_t \tag{6}$$

In our model, since there is no government expenditure, goods market clearing requires that $Y_t = C_t$.

The first order conditions are:

$$\xi_t C_t^{-\sigma} = \beta E_{t-d}\left\{\xi_{t+1}C_{t+1}^{-\sigma}\left(\frac{R_tP_t}{P_{t+1}}\right)\right\} \tag{7}$$

$$\frac{N_t^{\varphi}}{C_t^{-\eta}} = \frac{W_t}{P_t} \tag{8}$$

$$P_tC_t = W_tN_t + M_t - D_t \tag{9}$$

Where the first-order conditions respectively describe the optimal savings/consumption, labour supply decisions and the cash-in-advance constraint. Using the optimal savings/consumption condition from our maximization problem and substituting the resource constraint gives the familiar Euler equation. The log-linearized version yields the intertemporal IS:

$$y_t = E_{t-d}y_{t+1} - \frac{1}{\sigma}\left[E_{t-d}R_t - E_{t-d}\pi_{t+1}\right] + \frac{1}{\sigma}\left[\xi_t - E_{t-d}\xi_{t+1}\right] \tag{10}$$

where lower case variables denote the percent deviations from steady state, π the growth rate of the aggregate price index.

2.1 Firms

To model the price dynamics, we use Calvo's (1983) framework of staggered price setting. The model is described in detail in many papers and it has become the workhorse framework in the NK literature. We assume that a fraction $(1 - \omega)$ of suppliers can reset their price at the end of any given period. We introduce two assumptions that are different from the standard NK model. First, the assumed timing is different. In the model, the optimal price chosen by firms takes effect one period later. Firms must decide their prices at time t based on old information $t - 1$. Absent this timing issue, we revert back to the baseline model.

The second difference that we introduce is regarding how firms finance their wage-bill. We assume that firms may need to borrow to pay nominal wages. If this is the case, then a cost-channel of monetary policy arises in the model. Obviously, if firms never borrow in this model, we again revert back to the baseline model. We introduce a binary parameter γ that indexes whether or not there is a cost channel in the model.

Firms are assumed to produce a continuum of goods and operate in a monopolistically competitive market with decreasing returns to scale. The model abstracts from capital and assumes that the production function is given by:

$$Y_{it} = A_t N_{it} \tag{11}$$

where A_t is a technology shock and each firm is indexed by the subscript i. The real marginal cost of firm i, ψ_{it}, is:

$$\psi_{it} = \frac{W_t}{P_t}\left(\frac{R_t^{\gamma}}{A_t}\right) \tag{12}$$

The superscript γ is an index indicating whether there is a cost channel or not in the model. Setting $\gamma = 0$ indicates that there is no cost channel of monetary policy, whereas setting $\gamma = 1$ indicates the presence of a cost channel. Using the first order condition for the labour supply, the production function and the resource constraint, we can show that the log-linearized expression for the real marginal cost can be expressed as:

$$\psi_t = (\varphi + \sigma) y_t + \gamma R_t \tag{13}$$

We make the same assumptions as in Amato and Laubach (2003) and postulate that the fraction of firms that are allowed to change their price, that is $(1-\omega)$, do so optimally. However, only a proportion of these firms $(1-\nu)$ reset their prices optimally while the other proportion ν choose to optimize their price by setting it to last period's prices. These rule of thumb producers simply update their pricing by choosing the previous price level. Moreover, as previously discussed, we allow for predetermined pricing decisions and we assume that the price chosen by firms that are allowed to change their prices takes effect one period later. The log-linearized aggregate price index can therefore be written as a combination of firms that can and cannot change their prices:

$$p_t = \omega p_{t-1} + (1-\omega)\bar{p}_t^* \tag{14}$$

where $\bar{p}_t^*$ is the log-linearized price index of prices set in period t

$$\bar{p}_t^* = \nu p_t^b + (1-\nu) p_t^f \tag{15}$$

where the rule-of-thumb firms are denoted by the superscript b and the optimizing firms by the superscript f. The log-linearized index of prices is thus a convex combination of the prices set by the optimizing and forward-looking firms, the rule-of-thumb firms and firms that cannot change their prices.

As discussed in Amato and Laubach (2003) and Walsh (2003), the forward-looking price can be derived from the firm's decision problem. Doing so, one obtains the log-linearized condition

$$p_t^f = (1-\beta\omega)E_{t-d}(\psi_t + p_t) + \beta\omega E_{t-d}p_{t+1}^f \tag{16}$$

Note that because the price chosen takes one period to take effect, we have this different timing for expectations. The rule-of-thumb firms are assumed to set their prices according to the average price in the previous period corrected for past inflation. Thus, we obtain the log-linearized pricing decisions of the rule-of-thumb producers:

$$p_t^b = \bar{p}_{t-1}^* + \pi_{t-1} \tag{17}$$

where past inflation serves as the forecast for actual inflation. Using equations (14)-(17), we can derive the following hybrid NK Phillips curve.

$$\pi_t = \gamma^f E_{t-d}\pi_{t+1} + \gamma^b \pi_{t-1} + \kappa E_{t-d}\psi_t \tag{18}$$

Using the expression we derived for log linearized version of real marginal cost, we obtain our hybrid NK Phillips curve with a cost channel:

$$\pi_t = \gamma^f E_{t-d}\pi_{t+1} + \gamma^b \pi_{t-1} + \kappa E_{t-d}\left[(\varphi+\eta)y_t + \gamma R_t\right] + e_t \tag{19}$$

$$\begin{aligned}
\kappa &= \frac{(1-\nu)(1-\omega)(1-\beta\omega)}{\omega + \nu(1-\omega(1-\beta))} \\
\gamma^f &= \frac{\beta\omega}{\omega + \nu(1-\omega(1-\beta))} \\
\gamma^b &= \frac{\nu}{\omega + \nu(1-\omega(1-\beta))}
\end{aligned}$$

where e_t is a cost-push shock that we have added. This shock can be interpreted as an exogenous change in the desired wage and price markup as in Clarida et al (1999).

If $d = 0$ and $\nu = 0$, we obtain the familiar forward-looking New Keynesian Phillips curve since $\gamma^b = 0$ and $\gamma^f = \beta$. In this case current inflation is a function of the output-gap but more important of expectations about future inflation. Note that as ν tends to one, γ^b does not tend to one. This may lead us to conclude that γ^f remains positive even when $\nu = 1$. This is of course just a false impression. In the limit, as ν tends to one, equation (19) in fact collapses to an accelerationist Phillips curve with no forward-looking term.

2.2 The Different New Keynesian Models

The model nests the different specifications that we will be using in our analysis. We can rewrite our model in terms of the output-gap. Denoting x_t as the output-gap where the latter is defined as the difference between (log) output, y and the (log) natural level of output y_t^n. We obtain the following specification[4]

$$\begin{aligned}
x_t &= E_{t-d}x_{t+1} - \frac{1}{\sigma}\left(R_t - E_{t-d}\pi_{t+1}\right) + \tilde{u}_t && (20)\\
\pi_t &= \gamma^f E_{t-d}\pi_{t+1} + \gamma^b \pi_{t-1} + E_{t-d}\left(\kappa(\eta+\varphi)x_t + \kappa\gamma R_t\right) + e_t && (21)\\
x_t &= y_t - y_t^n && (22)\\
y_t^n &= \frac{1}{\sigma+\varphi}\left[(1+\varphi)a_t + \xi_t\right] && (23)\\
\tilde{u}_t &= \frac{1}{\sigma}\left[\xi_t - E_{t-d}\xi_{t+1}\right] + E_{t-d}y_{t+1}^n - y_t^n && (24)\\
e_t &= \rho_e e_{t-1} + \epsilon_t^e && (25)\\
a_t &= \rho_a a_{t-1} + \epsilon_t^a && (26)\\
\xi_t &= \rho_\xi \xi_{t-1} + \epsilon_t^\xi && (27)
\end{aligned}$$

Note that the disturbance $\tilde{u}_t$, is a composite demand shock that depends on the preference and productivity shocks.

2.3 Baseline and hybrid versions

When $d = \gamma^b = \gamma = 0$, we have the familiar forward-looking NK model with a forward-looking NK Phillips curve and a forward-looking IS curve. On the other hand, when $d = \gamma = 0$, $0 < \gamma^b, \gamma^f < 1$, we obtain the hybrid NK Phillips curve where both forward and backward-looking expectations about inflation are present.

2.4 Model with information lags

[4]When we have a cost channel in the model, the flexible price level of output is also affected by the flexible price level of the rate of interest. We assume that this is zero in the model with a cost channel.

Although the baseline NK model assumes that output and inflation respond instantaneously to changes in monetary policy, there is, however, ample empirical evidence from VARs that monetary policy affects output and inflation with considerable lags. The first extension to the baseline model we thus consider is a model with information delays. This model is obtained by setting $\gamma = 0$ and $d = 1$. The microfoundations of the model with lags in information are from Rotemberg and Woodford (1999) and Woodford (2003). The information lag is modelled by assuming that pricing decisions by firms take one period to have an effect. The fraction of firms that are allowed to change their prices under Calvo pricing must do so before the change takes effect. Under this specification, monetary policy does not have a contemporaneous effect on output and inflation.

2.5 Model with a cost channel

The second extension we consider is a cost-channel of monetary policy. The model with the cost channel is obtained by setting $d = 0$ and $\gamma = 1$ in equations (20) and (21). The microfoundations of the model with a cost channel we consider in this paper can be found in Ravenna and Walsh (2006). In their model, monetary policy affects inflation directly since higher interest rates have a direct bearing on marginal cost which in turn influences the inflation rate. One way to motivate the cost-channel is to assume that firms have to pay workers before receiving the proceeds from the sale of their goods and thus they have to borrow to settle their wage bill. In this case, monetary policy has a direct impact on the wage bill of firms, thus on their marginal cost and hence on inflation.

Numerous papers have shown that the cost channel is quantitatively important in the determination of inflation. For example, Barth and Ramey (2001) use industry level data and show that interest rates have a statistically significant effect on inflation through their effect on the marginal cost of firms. Ravenna and Walsh (2006) estimate a NK Phillips curve with a cost channel using GMM and provide empirical evidence in favour of a cost channel of monetary policy in the U.S.

2.6 Model with observational uncertainty - revisions in output and inflation

Many macroeconomic variables, most notoriously GDP, undergo important revisions over time. These revisions are known to be quite large and frequent. Whether or not these revisions can be forecastable is the subject of a growing literature on real-time data. Despite the difficulty to model the exact nature of the revision process, economists tend to agree that revisions of data do matter for the conduct of monetary policy and are large enough to have real economic consequences. For example, one of the leading explanation for the great inflation of the 1970s comes from Orphanides (2002) who argue that loose monetary policy coupled with misperceptions about potential output led to the rise in inflation during that period. We use a model where the central bank has accurate information about all the variables in the economy but noisy information on output and inflation.

We use the hybrid NK model ($0 < \gamma^b, \gamma^f < 1$ and $d = \gamma = 0$) except that we assume that the central bank has noisy information on output and inflation as they undergo revisions. We assume that output and inflation are revised over a sequence of three periods.[5] In the fourth period, the "true value" of output is revealed. Since the data revisions are not forecastable in this case, they are "news" to the policy-maker and the revisions are assumed to be orthogonal to the forecast value of output. The revision process is given by:

$$(y_t^o)^t = y_t + \theta_t^{3,y} + \theta_t^{2,y} + \theta_t^{1,y} \quad (28)$$

$$(y_t^o)^{t+1} = y_t + \theta_t^{3,y} + \theta_t^{2,y} \quad (29)$$

$$(y_t^o)^{t+2} = y_t + \theta_t^{3,y} \quad (30)$$

$$(y_t^o)^{t+3} = y_t \quad (31)$$

$$(\pi_t^o)^t = \pi_t + \theta_t^{3,\pi} + \theta_t^{2,\pi} + \theta_t^{1,\pi} \quad (32)$$

$$(\pi_t^o)^{t+1} = \pi_t + \theta_t^{3,\pi} + \theta_t^{2,\pi} \quad (33)$$

$$(\pi_t^o)^{t+2} = \pi_t + \theta_t^{3,\pi} \quad (34)$$

$$(\pi_t^o)^{t+3} = \pi_t \quad (35)$$

where y_t indicates the final or true level of output and $(y_t^o)^t$ represents the initial observation of output at time t (first vintage of the data), $(y_t^o)^{t+1}$ the revised estimate of time-t output published at time $t+1$, (second vintage of output), $(y_t^o)^{t+2}$ the revised estimate of time-t output published at time $t+2$ (third vintage of output). The same principle applies to inflation. The error terms $\theta^{i,j}$ where $i = \{1, 2, 3\}, j = \{y, \pi\}$ are the serially uncorrelated measurement errors with mean zero and diagonal covariance matrix given by $\Sigma_{\theta^{i,j}}$.

In this paper, we make the assumption that after three vintages, that is after three quarters, the central bank observes the final or true value of output. In reality, revisions

[5] This revision process is similar to Coenen, Levin and Wieland (2006) who investigate the role of money as an information variable for monetary policy when there is uncertainty about the data. We have considered revision process up to 8 periods. The results are qualitatively similar.

can last for many more periods and technically continue forever given changes in definitions and methodology.[6] The pattern of revisions we choose is somehow rich enough, however, to illustrate the importance of observational uncertainty on the stabilisation bias.

3 Optimal monetary policy

In the literature, monetary policy is often evaluated by a quadratic loss function that depends on the variances of inflation and the output-gap. Woodford (2003) has shown that such a loss function in a forward-looking NK model represents a second-order approximation of the utility of a representative agent. The relative weights on inflation and output-gap stabilisation are determined by the model's structural parameters. The loss function can be expressed as:

$$W = E_0 \sum_{t=0}^{\infty} \beta^t L_t \tag{36}$$

When expectations are completely forward-looking, the following loss function applies for all the different models, including the model with an information lag (see Woodford (2003), chapter 8), and a cost channel.

$$L_t = \pi_t^2 + \lambda_x x_t^2$$

where $\lambda_x = \frac{\kappa}{\alpha}$

When rule-of-thumb producers are present, the loss function is given by

$$L_t = \pi_t^2 + \lambda_x x_t + \lambda_\pi (\pi_t - \pi_{t-1})^2 \tag{37}$$

where $\lambda_\pi = \frac{\nu}{(1-\nu)\omega}$. This social welfare function is identical to that in Amato and Laubach (2003). With the rule of thumb producers, the welfare function depends also on the variance of the change in inflation. The central bank now cares not only about the volatility of inflation relative to the output-gap but also about the volatility of the change in inflation. Thus, the weight of inflation relative to the output-gap increases in the welfare function with the presence of rule-of-thumb producers. Looking at equation (37), it is clear that with a high value of α and a low value for κ, the weight that the central bank assigns to the output-gap in its objective function is very small.

[6] Lam (2009) considers other types of data revision processes, notably one where the measurement errors are serially correlated, reflecting the fact that the same vintage gets revised many times.

Rather than proceeding directly to numerical solutions, we derive whenever possible analytical results to obtain some intuition about the importance of commitment in these different models. Moreover, since analytical solutions cannot be derived in all cases and in cases when the model features forward and backward-looking expectations, all the derivations that follow assume a completely forward-looking model. We rely on numerical simulations to assess the importance of backward-looking expectations on the stabilisation bias and to draw conclusions from our models.

When the model is completely forward-looking, we can write the objective of the central bank as:

$$\max -\frac{1}{2}E_t\sum_{t=0}^{\infty}\beta^t\left(\pi_t^2+\lambda x_t^2\right) \tag{38}$$

subject to the forward-looking versions of equations (20) and (21) that is:

$$\begin{aligned} x_t &= E_{t-d}x_{t+1}-\frac{1}{\sigma}\left(R_t-E_{t-d}\pi_{t+1}\right)+u_t && (39)\\ \pi_t &= \beta E_{t-d}\pi_{t+1}+E_{t-d}\left(\kappa(\sigma+\varphi)x_t+\kappa\gamma R_t\right)+e_t && (40)\end{aligned}$$

The Lagrangean associated with this optimization problem can be written as:

$$L=E_0\sum_{t=d}^{\infty}\beta^{t-t_0}\left[-\frac{1}{2}\left(\pi_t^2+\lambda_x x_t^2\right)+\mu_{1t-d}\left(\pi_t-\beta\pi_{t+1}-\kappa(\sigma+\varphi)x_t-\kappa\gamma R_t\right)+\right.$$

$$\left.\mu_{2t-d}(x_t-x_{t+1}+\frac{1}{\sigma}\left(R_t-\pi_{t+1}\right))+\boldsymbol{tip}\right] \qquad \textit{where } \textbf{tip} \textit{ are terms independent of policy}$$

Except for the case involving the cost channel ($\gamma=1$), we can set the Lagrange multiplier associated with the intertemporal IS, μ_{2t-d} to zero. We do not need the intertemporal IS to solve for optimal policy when $\gamma=0$ and we can use x_t as the policy instrument.

3.1 Discretion

Under discretion, the optimization problem is equivalent to a period-by-period optimization and since the central bank does not make any promises about the future, it cannot influence the expectations of agents about inflation. Thus the optimization problem amounts to a single period maximization of the objective function subject to the model. The first-order conditions are given by:

$$\begin{aligned} \frac{\partial L}{\partial \pi_t} &= -\pi_t+\mu_{1t-d}=0 && (41)\\ \frac{\partial L}{\partial x_t} &= -\lambda_x x_t-\kappa(\sigma+\varphi)\mu_{1t-d}+\mu_{2t-d}=0 && (42)\\ \frac{\partial L}{\partial R_t} &= -\kappa\gamma\mu_{1t-d}-\frac{1}{\sigma}\mu_{2t-d}=0 && (43)\end{aligned}$$

3.2 Commitment

On the other hand, under commitment, the central bank makes a promise about its future actions. As a result, the future course of monetary policy is constrained (in a credible way). This implies that the central bank, under commitment, will optimize once and for-all taking the private sector expectations as given. The first-order conditions under timeless commitment are given by:

$$\frac{\partial L}{\partial \pi_t} = -\pi_t + \mu_{1t-d} - \mu_{1t-d-1} + \left(\frac{1}{\sigma\beta}\right)\mu_{2t-d-1} = 0 \quad (44)$$

$$\frac{\partial L}{\partial x_t} = -\lambda_x x_t - \kappa(\sigma+\varphi)\mu_{1t-d} + \mu_{2t-d} - \left(\frac{1}{\beta}\right)\mu_{2t-d-1} = 0 \quad (45)$$

$$\frac{\partial L}{\partial R_t} = -\kappa\mu_{1t-d} - \frac{1}{\sigma}\mu_{2t-d} = 0 \quad (46)$$

Note that in the case of the model with predetermined expectations, we can also write the first-order conditions in terms of forecast conditional upon information at time $t-1$.

3.3 Optimal policy in the baseline model

Optimal policy under discretion and commitment in the forward-looking NK model is easily derived using the first-order conditions above and setting the second Lagrange multiplier, μ_{2t-d} to zero. Doing so, we obtain:

$$\pi_t = -\frac{\lambda}{\kappa(\sigma+\varphi)}x_t \quad (47)$$

The condition implies that the central bank leans against the wind. An increase in inflation above its target implies that the central bank should engineer a negative output-gap and vice versa. Under commitment (from a timeless perspective), optimal policy is given by:

$$\pi_t = -\frac{\lambda}{\kappa(\sigma+\varphi)}(x_t - x_{t-1}) \quad (48)$$

Policy under commitment yields a superior outcome compared to discretion since it produces an inertial response that improves the trade-off between the output-gap and inflation. Under discretion, as shown in equation (47), the central bank's optimal policy is to lean against the wind by creating a negative output-gap to bring inflation back to equilibrium following a cost-push shock. The central bank trades-off a bigger output-gap for lower inflation by raising interest rates. It is clear from equation (47) that once the shock is over and inflation is back to equilibrium, the central bank has no incentive to keep the output-gap negative as this is costly in terms of welfare. This explains why optimal policy under discretion is not inertial.

On the other hand, as equation (48) shows, optimal policy under commitment consists of a credible promise to keep a negative output-gap, that is interest rates high, even after the shock has passed. By responding to the change in the output-gap and not the level, the central bank makes policy history-dependent and introduces an inertial response. Assuming that the central bank does not have the temptation to renege once the shock is over, by committing to keep the output-gap negative well beyond the life of the cost-push shock, this policy has the immediate effect of influencing inflation expectations and hence current inflation as the former is an important determinant of current inflation in the model. As a result, the central bank faces a better output-gap—inflation trade-off as a smaller decline in the output-gap is needed to decreased inflation in the commitment case. Clearly, this more favourable output-gap—inflation trade-off under commitment results in an overall improvement in welfare.

3.4 Optimal policy in the model with information lags

When there is an information lag in the model, the optimal conditions under discretion and commitment can be respectively summarized by:

$$\pi_{t|t-1} = -\frac{\lambda}{\kappa(\sigma+\varphi)} x_{t|t-1} \tag{49}$$

and

$$\pi_{t|t-1} = -\frac{\lambda}{\kappa(\sigma+\varphi)} (x_{t|t-1} - x_{t-1|t-2}) \tag{50}$$

where $\pi_{t|t-1}$ denotes private-sector expectations of π_t conditional on information available at time $t-1$. The optimal condition under discretion is the same as in the baseline case except that the condition is determined as of date $t-1$ instead of time t. This implies that the central bank leans against the wind by trading-off bigger output-gap for lower inflation but this time the central bank sets policy at time $t-1$ to achieve its stabilisation goals at time t. This change has an important implication for the discretionary outcome. $\pi_{t|t-1}$ and $x_{t|t-1}$ in this case will be affected by the past history of the exogenous shocks as well by $\pi_{t-1|t-2}$ and $x_{t-1|t-2}$. As a result, policy under discretion, when the model has an information lag, will feature some degree of inertia and history-dependence that is absent in the baseline model. As a result, policy under discretion in this model will display the same kind of history-dependence that is usually found under commitment. This implies that the stabilisation bias will be smaller in this case.

Moreover, compared to the baseline case, there is a key difference under commitment. When expectations are predetermined, promises made in the current period cannot immediately influence current and future values of output unless they are forecastable one period in advance. This is made clear by equation (50), the optimal condition under commitment. The change in the timing illustrates the inability of the central bank to affect the public's expectations about future inflation and output-gap at the time of announcement. This implies that the ability of the central bank to influence agents' expectations, which is a key reason why policy under commitment is superior to discretion in the first place, is affected in the model with information delays. As a result the overall effectiveness of commitment is affected, thereby also reducing the welfare gain from commitment.[7]

3.5 Optimal policy in the model with a cost channel

We derive optimal policy under discretion and commitment when the model has a cost-channel ($\gamma = 1$). The optimal conditions under discretion are:

$$\pi_t = -\frac{\lambda}{\kappa\varphi} x_t \tag{51}$$

and under commitment:

$$\pi_t - \pi_{t-1} = -\left(\frac{\lambda}{\kappa\varphi}\right)(x_t - x_{t-1}) + \left(\frac{\lambda}{\beta\varphi}\right) x_{t-1} - (1 + \frac{\sigma}{\beta\varphi})\pi_{t-1} \tag{52}$$

Some intuition on the consequences of the cost channel on the stabilisation bias can be obtained by examining the optimal conditions under discretion. With the presence of the cost channel, it is now more costly to stabilize inflation since changes in the policy rate have a direct bearing on inflation. If we examine the first-order conditions under discretion of the baseline and the model with the cost channel, that is equations (51) and (47), it is clear, that for a given change in the output-gap, inflation will react more when there is a cost channel compared to the case where there is no cost channel since $\frac{\lambda}{\kappa\varphi} > \frac{\lambda}{\kappa(\sigma+\varphi)}$.

The intuition for this result is fairly simple. In addition to the cost-push shock, the presence of the cost channel, introduces an additional source of trade-off that the central

[7] Lam and Pelgrin (2004) show that this result depends on whether spending and pricing decisions are predetermined to the same degree. They show that if pricing decisions are predetermined and not output, the gains from commitment can be large. On the other hand, if output is predetermined and not inflation, the gains from commitment are reduced. Kilponen and Leitemo (2007) also discuss the former result in their paper.

bank has to contempt with. It is more costly for the central bank to control inflation using its policy instrument. As a result, discretionary policy, by not being able to exploit private sector expectations about future inflation has to work even harder when there is a cost channel. On the other hand, although the central bank under commitment has to face this additional trade-off also, however, by appropriately influencing private sector expectations about inflation and hence current inflation, the central bank reacts less aggressively, thereby mitigating the impact of the cost channel on inflation. In short, with the cost channel, this expectations channel becomes even more important, making commitment that much more valuable. This result is similar to Ravenna and Walsh (2006).

The optimal commitment solution, although more difficult to interpret, provides another clue why the gains from commitment are larger in the presence of a cost channel compared to the baseline case. Recall that one of the benefits of commitment is that it introduces lagged output as a state variable, thus making the system inertial and history-dependent. Equation (52) reveals that the presence of the cost channel endogenizes the benefits of commitment even more since output and inflation in this case display additional persistence.

The presence of lagged inflation in the optimal solution under commitment imparts even more inertia in the policy response of the central bank. Because of the history dependence of inflation, the central bank has a bigger incentive to keep rates high for a long period of time once they are increased. As a result, this policy action of the central bank increases the importance of the expectations channel and the gains from commitment. This and the fact that the outcome under discretion when there is a cost channel is less favourable, explains why the gains from commitment are considerably larger in this case.

3.6 Optimal policy in the model with revisions in output and inflation

As outlined in Svensson and Woodford (2003), certainty equivalence continues to hold even in the presence of unobservables since the optimal solution of the model is independent of the stochastic shocks. As a result, we can apply the solution methods that we use in the full information case. To gain an intuition on the effects of the observational uncertainty on the stabilisation bias, we assume that the central bank observes an imperfect measure of output but has a perfect measure of inflation. In our present context, we assume there is a single period revision to output and this revision follows an *iid* process. Thus we have:

$$y_t^o = y_t + \theta_t^y$$

With both output and inflation being forward-looking variables in the model, the presence of a measurement error in output introduces a signal extraction problem for the central bank. This is because current inflation and output in the model depend respectively on current expectations of future inflation, future output and also on the current level of policy. The latter in addition to the current expectations of future inflation and future output, in turn, depend also on the current level of inflation and output. This leads to a circularity problem that the central bank has to deal with. As discussed in Svensson and Woodford (2003), this circularity problem can be solved by treating the optimization problem and the signal extraction problem faced by the central bank as separate.

When the central bank is faced with partial information on output, it can be shown that optimal policy under discretion and commitment is the same as in the case of full information except that the central bank now reacts to an efficient estimate of the current level of output which we denote by $y_{t|t}$.[8] Note that the central bank reacts to an optimal estimate of actual output and not to the observed level of output.

The optimal condition under discretion is given by:

$$\pi_t = -\frac{\lambda}{\kappa(\sigma + \varphi)} \left(y_{t|t} - y_t^n \right) \tag{53}$$

Under commitment, optimal policy is given by:

$$\pi_t = -\frac{\lambda}{\kappa(\sigma + \varphi)} \left[\left(y_{t|t} - y_t^n \right) - \left(y_{t-1|t-1} - y_{t-1}^n \right) \right] \tag{54}$$

Thus with a measurement error on output, optimal policy reacts to a noisy measure of the output-gap also. Here also, the central bank leans against the wind under discretion. However, with a measurement error in output, the central bank reacts to an optimal estimate of the output gap and not to its actual value. This innocuous change is however not benign and will affect the stabilisation bias in an important manner. Since the optimal estimate of current output and hence the output-gap will be a function of current and past observations of current variables, policy under discretion will display more inertia compared to the baseline case. In the latter case, policy under discretion reacts to current variables only and is not history-dependent. On the other hand, with a measurement error on output, policy under discretion becomes inertial. As a result, the stabilisation bias is affected and becomes smaller when the central-bank observes output (and inflation) with a noise.

[8] $y_{t|t}$ denotes the best estimate of y_t given the information available at time t.

With multi-period revisions in output and inflation, policy under discretion is likely to display even more inertia, thus reducing the size of the stabilisation bias and the inefficiency under discretion further. Based on these analytical results, however, it is difficult to draw any conclusions on how the discretionary outcome will be affected as we vary the size of the measurement error. We resort to numerical simulations to obtain an answer to this question.

4 Numerical Simulations and Results

Since obtaining analytical results under commitment when the model have backward and forward-looking expectations is prohibitively difficult, we resort to numerical simulations to evaluate the size of the stabilisation bias. The model can be written in state-space form and we use the solution methods provided by Soderlind (1999) to solve for the model with no measurement errors and those of Svensson and Woodford (2003) when the model features measurement errors. The model can be written as:

$$\begin{bmatrix} X_{t+1} \\ x_{t+1|t} \end{bmatrix} = A^1 \begin{bmatrix} X_t \\ x_t \end{bmatrix} + BR_t + \begin{bmatrix} C_\Theta \\ 0 \end{bmatrix} \Theta_{t+1} \tag{55}$$

$$Z_t = C_x \begin{bmatrix} X_t \\ x_t \end{bmatrix} + C_R R_t \tag{56}$$

and

$$L_t \equiv Q_t' W Q_t \tag{57}$$

where X_t is a vector of predetermined variables, x_t a vector of endogenous, forward-looking variables, R_t the central bank's policy instrument, Θ a vector of exogenous shocks hitting the economy, Q_t a vector of target variables and W a positive semidefinite matrix of weights that the central bank assigns in its objective function. A is a $(n\text{x}n)$ matrix containing the structural parameters of the model, B is a $(n\text{x}1)$ column vector, C_u, C_x and C_R are matrices of appropriate dimensions. The model is a standard linear stochastic problem with rational expectations and forward-looking variables. The solution methods provided by Soderlind (1999) can be applied to simulate the model.[9]

[9] Note that when we have the model with information lag, an expected future control term $B_1 R_{t+1|t}$ appears in the state-space. The linear stochastic problem can be easily accommodated to include the expected future control term. See Svensson (2000) for example.

When inflation and output are observed with a measurement error, we need to define the matrix of observable variables Z_t, that is output and inflation in our model.

$$Z_t = D^1 \begin{bmatrix} X_t \\ x_t \end{bmatrix} + D^2 \begin{bmatrix} X_{t|t} \\ x_{t|t} \end{bmatrix} + \theta_t \tag{58}$$

where θ_t is a vector of measurement errors. To solve the model with measurement errors we use the theory discussed in Svensson and Woodford (2000) and the algorithms of Gerali and Lippi (2003). The solution problem is similar to the certainty case except that estimates of the state vector are now needed because of the presence of unobserved variables. The optimal prediction for the unobservable state variables is computed by a Kalman filter. As outlined in Svensson and Woodford (2003), certainty equivalence continues to hold since the optimal solution of the model is independent of the stochastic shocks. Moreover, a separation principle applies, since the optimization and the signal extraction problems faced by the central bank are treated as separate problems.

4.1 Numerical values

To calibrate the model and perform our simulations, we assume the following values for the parameters of the model: β, the discount factor is set to 0.99, the labour supply elasticity φ is set to 1, ω, the fraction of firms that do not reset prices is set to 0.75, that is on average, prices are assumed to be sticky for a period of three quarters. α, the elasticity of substitution among goods is set to 6, σ, the relative risk aversion parameter is set to 1. We allow ν the parameter that governs the proportion of firms that are rule of thumb to vary between zero and one. The parameter γ which determines whether there is a cost channel or not is set to zero when the model does not feature a cost channel and to one when the cost channel is present.

We argued earlier that even as the proportion of rule of thumb producers, $\nu \to 1$, γ^f does not tend to zero but remains positive while γ^b does not tend to one. Since we want to analyze the gains from commitment when γ^b varies from zero (completely backward-looking Phillips curve) to one (completely forward-looking Phillips curve), we make two simplifications regarding the values that γ^b and γ^f take. First, we assume that γ^b and γ^f sum to one. There are two justifications for this assumption. If we assume that $\beta = 0.99$, ω equals 0.75, and if we allow ν to vary between 0 and 1, we find that the sum of γ_b and γ_f is always close to one. Moreover, to analyse the importance of backward versus forward-looking expectations, we find it more informative to simulate our model when these two coefficients sum to one. Second, in order to force γ^b to go to one when $\nu = 1$, we assume that $\gamma^b = \nu$ and thus $\gamma^f = 1 - \nu$. If we assume that ω=0.75 and $\beta = 0.99$, we find that the true value of γ^b is close to ν as long as the latter is less than 0.5. Finally, we fix the value of κ to 0.05 (a value commonly used in the literature) instead of allowing it to vary.

Regarding the shocks, the variance of the preference and cost-push shocks are both set to 0.015 while the variance of the technology shock is set to 0.03. The persistence parameters ρ_e is set to 0.5 initially and $\rho_a = \rho_\xi$ equal 0.97. We provide some robustness tests by varying the size of the persistence parameter as well as the size of the variance.

When data revisions are present, we assume that the variance of the measurement errors for output is identical for the three periods and is equal to a fifth of the variance of the technology shock. The variance of the measurement errors for inflation is also assumed to remain constant for the three periods and is set equal to a tenth of the variance of the technology shock or half the size of the variance of the measurement errors on output. We assume a bigger variance on the measurement errors for output compared to inflation since there is evidence (see Croushore (2009) for example) that data revisions on output are larger than those on CPI. We provide some robustness tests by allowing the variance of the measurement errors to vary.

4.2 Results

The results of the simulations are presented in Figure 1. This figure shows the percentage gain when the central bank commits rather than acts under discretion, that is the size of the stabilisation bias. We obtain the following results:

(a) The size of the stabilisation bias, irrespective of the model utilized, increases as inflation expectations become more forward-looking. The gains from commitment increase monotonically as γ^f approaches one. This result is not new and has been well documented in the literature and the intuition for this result is clear and has already been explained in the introduction.

(b) The size of the stabilisation bias is zero when inflation expectations are completely backward-looking, except in the model with the cost-channel. The intuition for this result comes from the presence of forward-looking consumers. Introducing the cost channel increases the importance of forward-looking behaviour in a very direct way since current inflation depends not only on expected inflation as in the standard New Keynesian framework, but also directly on the expected output-gap. This is illustrated by substituting equation (20) in equation (21) :

$$\pi_t = ((1-\gamma^b)+\kappa)E_t\pi_{t+1} + \gamma^b\pi_{t-1} + \kappa\gamma\sigma E_t x_{t+1} + \kappa\varphi x_t + \kappa\sigma u_t + e_t \tag{59}$$

It is clear from equation (59) that even if price setting decisions are completely backward-looking in the model with a cost channel, that is $\gamma^b = 1$, a stabilisation bias remains since current inflation still depends on expected future outcome, thus making commitment valuable. This result is similar in spirit to Leitemo, Røisland, and Torvik (2006), who show that the stabilisation bias remains important in a model where the aggregate supply function is completely backward-looking and the exchange rate is the only forward-looking variable.

(c) The size of the stabilisation bias is considerably reduced when the baseline model is modified to include an information lag. They are approximately 10% in the model with an information lag compared to around 50% in the baseline model when inflation expectations are forward-looking. The introduction of an information lag reduces the benefits of commitment. This is because when monetary policy affects the economy with a lag, policy-makers are less able to make promises to offset shocks and thus it reduces efficacy of credible commitments.

Moreover, as discussed in section 3.4, policy under discretion in this case will be more inertial compared to the baseline model. This is because optimal values for inflation and the output-gap, when there is an information lag, depend on past observations of the exogenous shocks and previous expected values of themselves. This display of history dependence under discretion thus reduces the size of the stabilisation bias.

There is a third reason that might explain why the stabilisation bias is smaller in this case. In a framework with information lags, the central bank can no longer perfectly insulate the economy from demand shocks unless they are perfectly forecastable. It is well known that commitment is valuable when the central bank faces shocks that imposes a trade-off on society. On the other hand, when shocks such as demand and technology—that pose no trade-off to society—become increasingly important as in the framework with information lags, the need for commitment is greatly reduced. This result is, however, not entirely obvious from our first-order conditions.

(d) When the cost channel is introduced, the size of the stabilisation bias is greatly increased. This result is intuitive. With the cost channel, stabilizing inflation is now more costly since the central bank faces a trade-off not only from the cost-push shock but also from the presence of the cost channel itself. In the conventional NK model, to trade lower output for lower inflation, the central bank increases interest rates. Lower inflation is achieved as the output-gap shrinks.

With a cost channel, higher interest rates serve to shrink the output-gap but they also have a direct bearing on inflation itself. The presence of the cost channel will thus partly offset any negative effect higher interest rates will have on inflation. As a result, the central bank will have to work harder to bring inflation down, thereby causing more volatility in inflation itself. The bigger the cost channel, the stronger will be the direct effect of interest rates in inflation. Since it is now more costly for central banks to trade output-gap movements for greater inflation stability, under discretion, the central bank will tend to over-stabilize the output-gap and under-stabilize inflation even more, thereby exacerbating the stabilisation bias. The first-order conditions we derived earlier clearly illustrate this point.

Commitment is very valuable in this case since by merely promising to keep rates high, the central bank does not need to work as hard to bring inflation down. The size of the trade-off that it faces is attenuated because the expectations channel is contributing to the reduction of inflation. Thus the presence of the cost channel increases the gains from commitment and hence the stabilisation bias.

(e) The stabilisation is reduced in the model with an unobservational uncertainty on output and inflation. The loss function under discretionary policy in this case is around 25% higher compared to the commitment case when inflation expectations are forward-looking. When compared to the baseline case, the size of the stabilisation bias is reduced by about half. As discussed in section 3.6, with noisy observations on output and inflation, the central bank reacts to estimates of output and inflation. These estimates depend on current observed variables but more importantly on past observations of current variables. Thus, optimal policy under discretion in the presence of measurement errors depends not only on contemporaneous variables but more importantly on past observations. As a result, policy under discretion becomes inertial and will display the same kind of history-dependence that is usually found under commitment. According to our numerical results, this has a significant reduction on the size of the stabilisation bias.

(f) In all models, as shown in Figures 2-4, we find that the size of the stabilisation bias increases as the cost-push becomes more persistent. This result is similar to Clarida et al. (1999) and is fairly intuitive. As the cost-push shocks become more persistent, the ability of the central bank to offset the cost-push shocks is impeded. Making credible commitments to lower inflation in the future becomes more valuable in this case since the central bank can lower inflation without resorting to large increases in interest rates. This channel is absent under discretion since the central bank cannot influence the expectations of agents about inflation. As a result, the central bank faces a less favourable output-gap inflation trade-off as the cost-push shock becomes more persistent, resulting in a larger stabilisation bias.

(g) As shown in Figure 5, the size of the stabilisation bias decreases as the size of the measurement errors increases. When the size of the measurement errors increase, the signal extraction problem that the central bank faces gets more complicated and costly. In this case, the central bank optimal reaction becomes even more inertial under discretion, further reducing the size of the stabilisation bias and the inefficiency that arises under discretionary policy. If this is the case, then the need for optimal delegation may be attenuated. This is certainly a topic for future research.

5 Conclusions

How important is commitment in the NK model? According to our results, there are significant gains if the central bank can credibly commit. Except for the model where there is a delayed response in monetary policy, we find that for forward-looking inflation expectations, the gains from commitment are large. All the other modifications we brought to the baseline model indicate that there are significant gains from commitment as long as expectations are predominantly forward-looking. In the model with the cost-channel for example, there is a 150% improvement in the welfare function from commitment, about three times more compared to the baseline case. One of the main results of this paper is that the gains from commitment depend on many factors and not just on the degree of backward versus forward-looking expectations about inflation that many previous papers have emphasized. Factors that accentuate the trade-off that the central bank faces, in addition to the cost-push shock, actually increase the size of the stabilisation bias. On the other hand, factors that reduce the efficacy of commitment and that make promises less valuable tend to decrease the size of the stabilisation bias. In future work, it would be interesting to incorporate some of the features we discussed in this paper and estimate the model. We may then get more information on the importance of each of these channels for the stabilisation bias.

Figure 1: Size of stabilisation bias

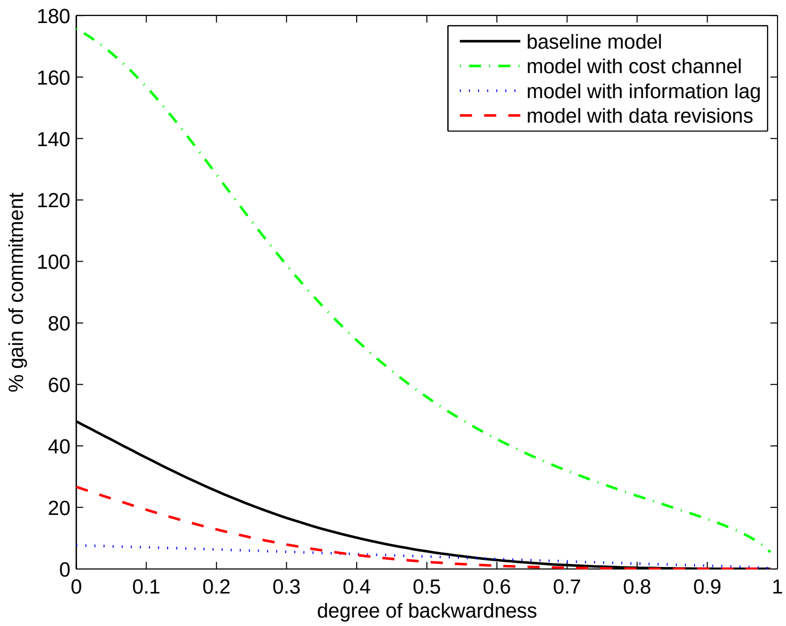


Figure 2: Size of stabilisation bias when the degree of serial correlation of the cost-push shock changes - Baseline model

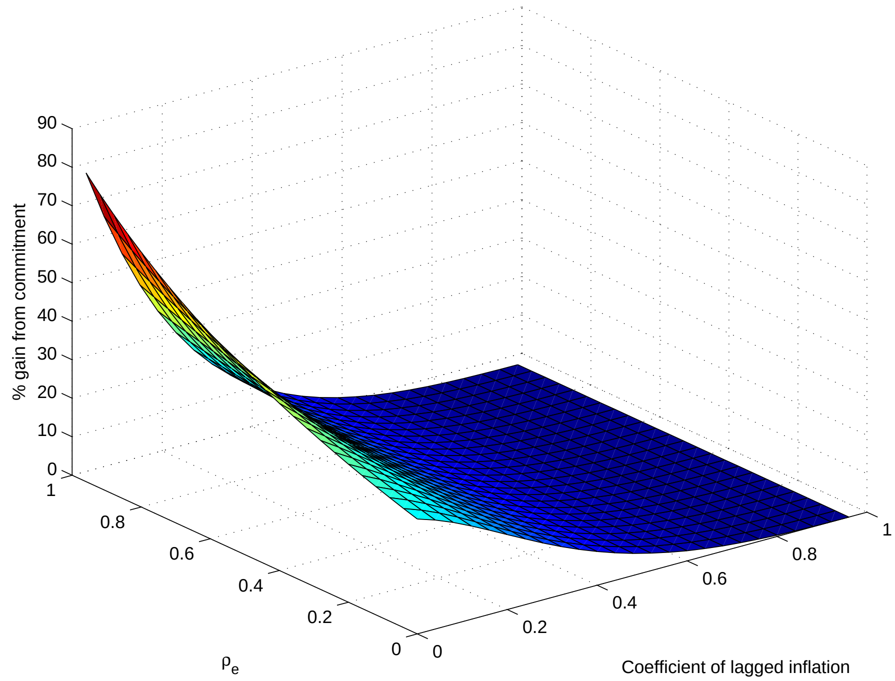


Figure 3: Size of stabilisation bias when the degree of serial correlation of the cost-push shock changes - cost channel model

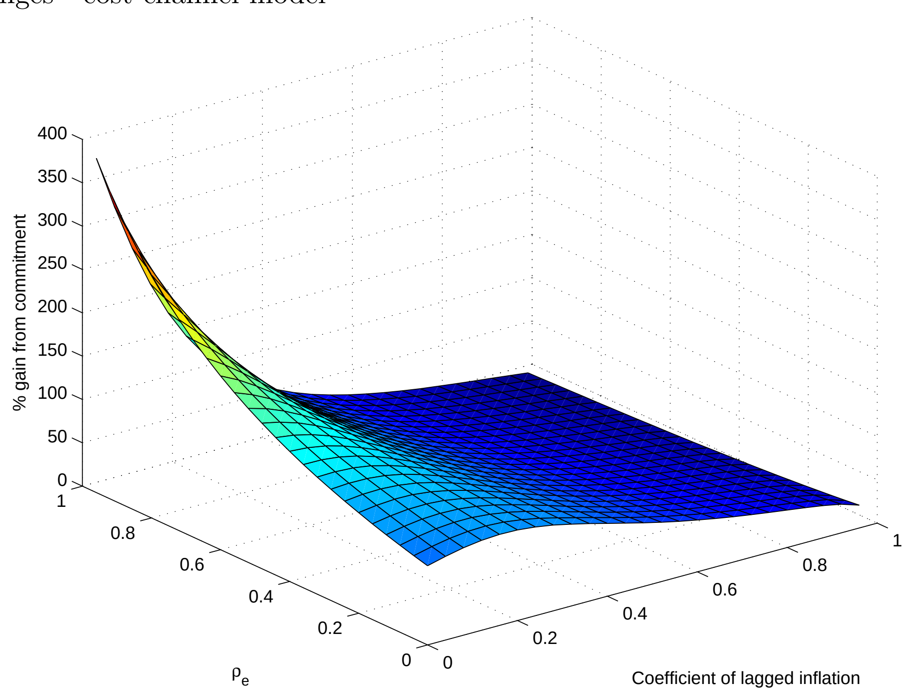


Figure 4: Size of stabilisation bias when the degree of serial correlation of the cost-push shock changes - revision data model

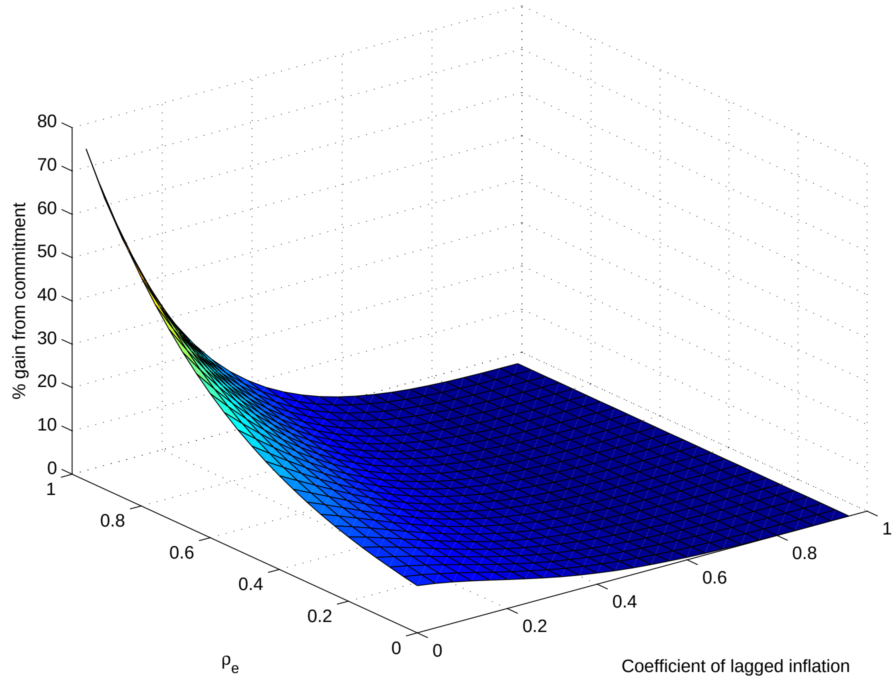
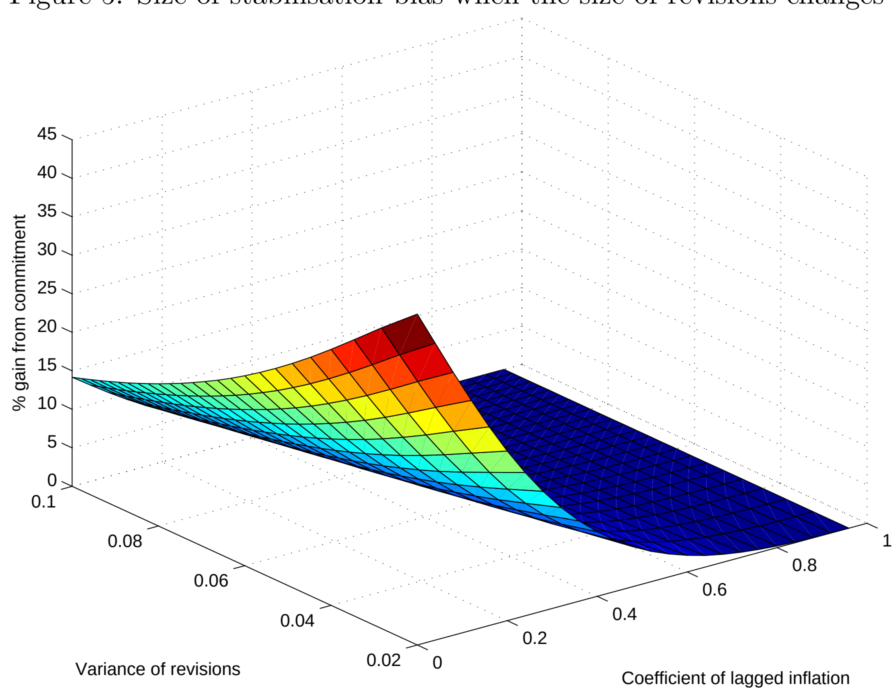


Figure 5: Size of stabilisation bias when the size of revisions changes



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