New Keynesian Microfoundations Revisited: A Generalised Calvo-Taylor Model and the Desirability of Inflation vs. Price Level Targeting

Richard Mash

Department of Economics and New College
University of Oxford

Preliminary draft: January 2002

Abstract

Optimal monetary policy is sensitive to the Phillips curve used to represent the dynamics of inflation and output. Most recent literature has used a New Keynesian Phillips Curve based on Calvo pricing. This paper shows that this workhorse model is not robust to relatively minor changes in its microfoundations, in particular allowing for time varying probabilities of a firm being able to reset its price. We derive a general model that nests Calvo and the Taylor staggering model as special cases and analyse its implications for optimal policy, including the relative desirability of inflation and price level targeting.

Key Words

New Keynesian Phillips Curve, Stabilisation Bias, Forward Looking Expectations, Inflation Targeting, Price Level Targeting, Calvo Pricing.

JEL Classification Numbers

E52, E58, E22, C61

Contact Details

Dr Richard Mash

New College, Oxford, OX1 3BN, UK

Tel. +44-1865-289195

Fax. +44-1865-279590

email address: richard.mash@economics.ox.ac.uk

www.economics.ox.ac.uk/People/Members/MashRTB.htm

Introduction

The monetary policy literature has made rapid progress in recent years in analysing the consequences for optimal policy of the presence of forward looking inflation expectations in the Phillips curve or aggregate supply relationship. When commitment is feasible optimal policy in response to a supply shock adjusts future policy to improve current outcomes through the intertemporal link of expected future inflation in the Phillips curve.[1] From the point of view of the future taken in isolation such a policy is costly (and hence is not generally carried out under discretion, resulting in stabilisation bias) but optimal policy balances these future costs against current benefits. Clearly the strength of the intertemporal link in the Phillips curve, primarily the size of the coefficient on expected future inflation, is important for optimal policy as well as more generally for our understanding of macroeconomic dynamics.

This paper analyses the microfoundations of the Phillips curve and the coefficient on expected future inflation in particular, showing that the standard value of close to unity used in the literature from Calvo pricing is not robust to plausible and relatively minor changes in its microfoundations. The paper presents a generalised version of the Phillips curves used in the literature that may provide a better basis for policy analysis and shows its implications for optimal policy. The common theme is fully optimising microfoundations but with different exogenous staggering structures, motivated in part by concerns about the robustness of the Calvo

---

[1]See Clarida, Gali and Gertler (1999) and Woodford (2000) for summaries. A growing literature assesses how improved stabilisation may be achieved under discretion (when intertemporal commitment is generally infeasible) by altering the loss function to be minimised under delegation by an independent central bank. These include interest rate smoothing (Woodford, 1999), nominal income growth targeting (Jensen, 1999; Rudebusch, 2000) and targeting the change in the output gap (Soderstrom, 2001; Walsh, 2001).

model (see Wolman, 1999; Dotsey, King and Wolman, 1999, for recent discussion and results) and more generally by the empirical evidence presented in Taylor (1999) who emphasises the observed richness and variety of price and/or wage staggering structures and our comparative ignorance of how to model them most accurately. McCallum (199) suggests that aggregate supply is the least well understood component of monetary policy models.

It is helpful to briefly review the use of the New Keynesian Phillips curve in the monetary policy literature before setting out the contribution of the current paper in more detail. The Calvo (1983) model, which gives rise to a New Keynesian Phillips curve of the form shown by (1), has become the workhorse for much recent research.[2] In (1) π is the rate of inflation, β the (real) discount factor which is close to unity, x the driving variable (such as the output gap or marginal cost), κ a constant and u a shock variable.

$$\pi_t = \beta E_t[\pi_{t+1}] + \kappa x_t + u_t \tag{1}$$

Price staggering in the Calvo model is introduced by firms only being able to reset their prices at stochastic times and a simplifying assumption is made that the probability of being able to reset price in a given period is constant and unrelated to the time that has elapsed since the last price change. Clearly this is a strong assumption but use of the model has been encouraged by broad similarities between its properties and those of other models of price staggering. For example Rotemberg's (1987) model of convex price adjustment costs also leads to a Phillips curve of the Calvo form, though Rotemberg regards convex price adjustment costs as a simplifying rather than fundamental assumption in much the same way as Calvo (1983) presents

[2]For example see Clarida, Gali and Gertler (1999), Svensson (1999), McCallum and Nelson (1999a, b) and Rotemberg and Woodford (1999).

the constant probability of price change assumption.

A number of authors (for example Roberts, 1995, and Walsh, 1998) have also pointed to broad similarities between the Calvo model and that of Taylor (1979, 1980) where price changes are also staggered but are simply fixed for two (or more) periods at a time. If it was the case that both the Calvo and Taylor models, with their different staggering assumptions, predicted the same form for the Phillips curve it would be strong evidence that the details of staggering structures are not very important but we show that this is not the case, particularly in the presence of supply shocks which present the most acute problems for policy makers. Under perfect foresight the Taylor model is similar to the Calvo case (1), and has an identical coefficient on expected future inflation. If shocks are present, however, Taylor staggering gives the Phillips curve (2) in which $E_{t-1}[B_t]$ is present and the coefficient on $E_t[B_{t+1}]$ is approximately half its value in (1).[3,4] This has very different implications for optimal policy compared with (1) given the discussion above about the role of this coefficient in influencing the optimal extent to which policy should commit to different future outcomes in order to affect the present.

---

[3] The Taylor Phillips curve is sometimes presented (see Roberts, 1995, and Walsh, 1998, eqn. (5.45) p.217 for example) in the form of (1) but with an additional 'expectational error' term on the right hand side involving $E_{t-1}[B_t]-B_t$ (which is zero under perfect foresight but not otherwise). This 'error' is sometimes combined with the shock term, u_t, to form a composite error. This is algebraically correct but it is misleading if this error is subsequently treated as exogenous. On average under rational expectations the expectational error should be zero but its size in any given time period, and thus its effect on the Phillips curve, is endogenous to time t policy because $E_{t-1}[B_t]$ is pre-determined at t whereas B_t is not. Hence treating the error as if it is zero or exogenous overstates the true coefficient on $E_t[B_{t+1}]$ in the Phillips curve.

[4] The driving variable and shock terms also take a more complex form in the Taylor model. These are explored thoroughly below but for now the focus is on the terms in expected inflation and hence we use the general form f(x,u) in (2). Kiley (1998) draws attention to the general differences between the Calvo and Taylor models but without explicit reference to the different coefficients on expected inflation in (1) and (2) and their implications for optimal policy.

$$\pi_t = \frac{\beta}{1+\beta}E_{t-1}[\pi_t] + \frac{\beta}{1+\beta}E_t[\pi_{t+1}] + f(x,u) \qquad (2)$$

Given that the Calvo and Taylor Phillips curves differ significantly in the presence of supply shocks it appears that we are in the uncomfortable position of having divergent predictions for the Phillips curve from different assumptions about price staggering when there seems little compelling reason to find one or other more plausible. In terms of these models it also appears to be a binary choice with strong implications for the policy conclusions that will follow. Given this choice a common stance is to choose the Calvo Phillips curve (1), primarily because the Calvo model has more explicit microfoundations than the standard derivation of the Taylor model (see Clarida, Gali and Gertler, 1999, and the discussion in Walsh, 1998, for examples). We show below, however, that the latter may be derived from exactly the same microfoundations as Calvo, the difference between the two arising solely from different exogenous staggering constraints faced by optimising agents.

The main contribution of this paper is to show that the Calvo and Taylor models may both be viewed as special cases of a more general model that we derive below. This clarifies the reason for their different predictions for the Phillips curve, which arise solely from their different assumptions about price change staggering, and clarifies that their underlying microfoundations are the same apart from the staggering structure. The generalised model follows the Calvo approach of making firms' ability to change price stochastic, but rather than the probability of being able to change price remaining constant we allow it to take a different value one period after a price change (q_1) than the per period probability thereafter (q). This simple generalisation (which by no means exhausts all possibilities[5]) encompasses the Calvo model for which q_1=q and the Taylor model where q_1=0 and q=1 (for two period fixed prices). Defining $q^*=q-q_1$, where q^* is zero in Calvo and unity in Taylor, allows the generalised Calvo-Taylor Phillips curve (derived in full below) to be expressed by (3) where for the time being we focus on the terms in expected inflation and leave the driving variable and shock terms in general form.

$$\pi_t = \frac{\beta q^*}{1+\beta q^*} E_{t-1}[\pi_t] + \frac{\beta}{1+\beta q^*} E_t[\pi_{t+1}] + g(x,u) \qquad (3)$$

From (3) it is clear that the generalised model has coefficients on $E_{t-1}[\pi_t]$ and $E_t[\pi_{t+1}]$ that vary with q^* ($0 \leq q^* \leq 1$) between those in (2) and (1) above of approximately a half each and zero for the former and close to unity for the latter. Thus the generalised model clarifies the similarities and differences between the Calvo and Taylor models individually while suggesting that it is not appropriate, given our limited understanding of the most realistic way to model price staggering (and pending further empirical evidence), to choose one or the other. Instead it appears that good practice requires monetary policy analysis to check the sensitivity of results to variation in the expected inflation coefficients in the Phillips curve at least between the ranges suggested above.[6]

To explore the implications of different staggering structures for the Phillips curve further we also derive a version of the generalised model in which wages rather than prices are staggered, the latter being fully flexible ex post in this case. We show that this reversal of the roles of the two key nominal variables makes no difference to the coefficients on the first two terms in (3).

---

[5]Wolman (1999) considers a richer structure of probabilities though without explicit results for the Phillips curve or optimal policy.

[6]Mankiw and Reiss (2001) derive a Phillips curve from a different approach in which the term in $E_t[\pi_{t+1}]$ disappears altogether.

This is a standard result with Taylor staggering but less familiar with Calvo probabilities and new for the generalised model. We also show the consequences, for the staggered prices version of the generalised model, of wages being partly set in advance rather than being flexible ex post. This is in the spirit of the models of Barro and Gordon (1983) and Rogoff (1985) except that ex ante wage setting coexists with price staggering. In this case the coefficient on $E_{t-1}[B_t]$ increases relative to that in (3) and that on $E_t[B_{t+1}]$ falls further.

We also note two aspects of the literature which we do not address in the paper. The first is that it has become increasingly common to introduce some inflation persistence (through a term in B_{t-1}) into the Phillips curve. This is motivated primarily by the strong empirical evidence for persistence in the inflation process (see Rudebusch, 2000, and Roberts, 2001 for excellent summaries and fresh empirical results) but as yet there is no consensus on optimising microfoundations for this.[7] The focus of this paper is the different forms of the Phillips curve that emerge from different staggering structures with common optimising microfoundations. Hence we do not consider inflation persistence directly while noting that, i) the generalised Calvo-Taylor model does not have any structural inflation persistence in the sense that B_{t-1} does not appear in the Phillips curve (except when wages are set partly ex ante and then as part of a time t-1 expectation error which may be considered exogenous to time t policy choices), but ii) under discretion inflation has some serial correlation in univariate reduced form. The latter is

[7]The approach to this issue of Christiano, Eichenbaum and Evans (2001), Sbordone (2001) and Woodford (2001), who introduce price or wage indexing, appears very promising but it appears to be too early to regard these models as widely accepted. If optimising microfoundations for inflation persistence emerge from time dependent staggering the generalised model of this paper (which could be extended to include indexing behaviour) will also contribute to this research program.

not the case in the Calvo model but may contribute to observed inflation persistence in practice.[8]

The second restriction of scope is that we consider only time dependent pricing behaviour. While Ball and Ceccheti (1988) and Ball and Romer (1989) showed that staggering may emerge as an equilibrium[9] it might be argued that state dependent pricing models are more theoretically attractive. While sympathetic to this view, the stance taken in this paper is that the implications of state dependent pricing for the Phillips curve are not fully understood and hence pending further progress (see Dotsey, King and Wolman, 1999, for a recent contribution), and given the use of time dependent pricing in most of the monetary policy literature, it remains important for us to understand the robustness of the workhorse Calvo model and the impact of different time dependent staggering structures more generally.

While the prime contribution of the paper is the derivation of the generalised Calvo-Taylor Phillips curve model we also derive optimal policy for the model in the presence of supply shocks. This confirms the link between the coefficient on $E_t[B_{t+1}]$ in the Phillips curve and the

---

[8]The criticism in footnote 1 of some interpretations of the Taylor model extends to the usual presentation of the Fuhrer-Moore (1995) relative real wage contracting model also. This model is often used as the basis for introducing inflation persistence. With a discount factor of unity for simplicity and considering only terms in inflation, the Fuhrer-Moore Phillips curve is usually reported (for example see Walsh, 1998, eqn. (5.62) p. 225) as $B_t=½(B_{t-1}+E_t[B_{t+1}]]+0_t/2$ where $0=E_{t-1}[B_t]-B_t$. The expectational error 0_t is sometimes taken as exogenous or zero or rolled into a composite error term with the truly exogenous shock variable (see for example the definition of $,_{5t}$ in eqn. (8) of Batini and Haldane, 1999). As in footnote 1, $E_{t-1}[B_t]$ is pre-determined at time t whereas B_t is not and hence their difference should not be treated as exogenous at time t (except under perfect foresight which is not usually the case of interest). Making 0_t explicit gives the inflation terms in the Fuhrer-Moore Phillips curve when shocks are present by $B_t=(1/3)(B_{t-1}+E_{t-1}[B_t]+E_t[B_{t+1}])$.

[9]Bhaskar (1999) summarises arguments questioning these results while providing an additional mechanism to support them.

extent to which policy should alter its future course in order to affect current outcomes. In particular we examine the result of Clarida, Gali and Gertler (1999) who showed that with a simple Calvo Phillips curve and a standard policy loss function involving fluctuations in the output gap and inflation about target, optimal policy involves a stationary price level.[10] If an inflation increasing shock occurs at time t, optimal policy commits to inflation below its (zero) target next period in order to influence the value of $E_t[B_{t+1}]$ and thus the time t inflation-output tradeoff. The combined effect of these inflation rates, together with the optimal subsequent return to zero inflation, is that the sum of the inflation rates (which corresponds to the cumulative change in the price level) from the time of the shock into the infinite future is zero (except in so far as further shocks in the future may peturb that path). Hence based on the assumption of a Calvo Phillips curve, optimal monetary policy with inflation rates in the loss function implies price level targeting type policy choices. We show that this result no longer holds in the generalised Calvo-Taylor model and while it remains optimal to have a lower inflation rate than otherwise the period after an inflation increasing supply shock the optimal path no longer fully offsets the initial impact of the shock on the price level.[11]

This result complements the same finding by Jensen (1999) when inflation is persistent (which is also implicit in Steinsson, 2000) but shows that the optimality of price level targeting is not robust even without inflation persistence. Given the continued controversy about the degree of inflation persistence this result suggests very strongly that a cautious approach is required before

---

[10]See also Dittmar and Gavin (2000) and Goodfriend and King (2001).

[11]An assessment of the various mechanisms that have been proposed to achieve appropriate 'policy inertia' (see footnote 1) in the new generalised model is beyond the scope of this paper but it seems highly likely that the reduced coefficient on expected future inflation in the Phillips curve reduces the optimal degree of inertia (though not to zero).

advocating price level targeting (see King, 1999) and is also highly relevant for the ongoing debate about the appropriate objectives for the European Central Bank discussed by Alesina et. al. (2001) amongst others. More generally the policy results are supportive of the mixed inflation-price level targeting approach of Nessen and Vestin (2000) and Batini and Yates (2001).

The paper is structured very simply in that Section 1 derives the generalised Phillips curve model when either prices or wages are staggered (but with the other flexible), Section 2 analyses the case of staggered prices with wages partly set ex ante, and Section 3 shows the implications of the analysis for optimal policy and inflation vs. price level targeting in particular. Section 4 concludes while the appendices contain supplementary material, including detailed microfoundations for optimal price and wage setting behaviour to emphasise that the Phillips curve models derived share common optimising microfoundations, their differences arising from different staggering constraints.

1. The Generalised Calvo-Taylor Model

This section derives the generalised Calvo-Taylor model, initially for the case where prices are staggered but wages are fully flexible, before showing that similar results obtain if these roles are reversed. We consider the price setting decision of a firm that is able to change its price at time t subject to the exogenous probabilities of being able to change price again in the future of q_1 the following period and q each period thereafter assuming that the price has not already been changed again. As noted above the special case of q_1=q recovers the Calvo model and q_1=0, q=1 corresponds to the Taylor model. Having derived and simplified the optimal price for a single firm we substitute for these individual prices into the appropriate expression for inflation given this staggering structure (derived in Appendix B) to generate the Phillips curve for this model. Appendix A gives microfoundations for optimal single period behaviour upon which the multi-period optimisation under staggering constraints is based.

We follow the standard discrete time solution procedure for the Calvo model (as in Rotemberg, 1987 and summarised in Walsh, 1998, p.218-220) subject to the different probability structure noted above.[12] Based on a second order Taylor series for profits as a function of price this approximates the firm's optimisation by the minimisation of the expected discounted and probability weighted sum of a per period loss function that is quadratic in the difference between the logs of the firm's price and the ideal single period price. The latter is derived in Appendix A, denoted p* and corresponds to the price which the firm would set in that period in the absence of constraints on changing prices in the future. This term for each period is discounted by the (real) per period discount factor, β, and weighted by the probability of the price set at time t still being in place in each subsequent period, t+j. This probability is simply $(1-q_1)(1-q)^{j-1}$ for $j \geq 1$ and unity for j=0. The optimisation need not consider what happens after the firm has been able to reset its price since the choice of price at time t does not constrain that subsequent optimisation. Hence the firms choice problem may be expressed by (4) where L^f is the total loss function for firm i and x_{it} the price it sets at t.

---

[12] We also follow Rotemberg (1987) and the standard forms of the Calvo and Taylor models in assuming that new prices in a given time period are set ex post on the basis of information available in that time period. This contrasts with the original papers by Fischer (1977) and Taylor (1979) where new prices or wages were set the previous period. Rotemberg and Woodford (1997) allow for some agents (in an otherwise Calvo framework) to have to set prices on the basis of previous period information. This reduces the importance of time t dated expectations in the Phillips curve and thus the potential gains from intertemporal commitment. In Section 2 we allow for a proportion of wages to be set ex ante while new prices remain set ex post which has a similar effect.

$$Min_{x_{it}} \; L_i^f = E_t \left[(x_{it}-p_t^*)^2 + \sum_{j=1}^{\infty} \beta^j (1-q_1)(1-q)^{j-1} (x_{it}-p_{t+j}^*)^2 \right] \tag{4}$$

The first order condition for (4) is given by (5) which shows that the optimal price set by a firm at time t depends on the current and expected future optimal single period prices, appropriately weighted by the discount factor and the probability of the time t price still being in effect in future periods. For convenience we use the notation $q^*=q-q_1$ which is zero in the Calvo model and unity in the Taylor model while unrestricted here.

$$x_{it} = \left[\frac{1-\beta(1-q)}{1+\beta q^*}\right]\left[p_t^* + \frac{(1-q_1)}{(1-q)} E_t\left[\sum_{j=1}^{\infty} \beta^j (1-q)^j p_{t+j}^*\right] \right] \tag{5}$$

From this point we may drop the i subscript due to symmetry across firms that are changing their prices at the same time. It is convenient to take the period t+1 out of the last term in (5) to give (6).

$$x_{it} = \left[\frac{1-\beta(1-q)}{1+\beta q^*}\right]\left[p_t^* + (1-q_1)\beta E_t[p_{t+1}^*] + \frac{(1-q_1)}{(1-q)} E_t\left[\sum_{j=2}^{\infty} \beta^j (1-q)^j p_{t+j}^*\right] \right] \tag{6}$$

Next we shift (5) one period ahead to give the optimal x_{t+1} and take expectations of this at t to give (7).

$$E_t[x_{t+1}] = \left[\frac{1-\beta(1-q)}{1+\beta q^*}\right] E_t\left[p_{t+1}^* + \frac{(1-q_1)}{(1-q)} \sum_{j=2}^{\infty} \beta^{j-1} (1-q)^{j-1} p_{t+j}^* \right] \tag{7}$$

In turn (7) may be rearranged to give (8), the right hand side of which is the same as the last term in (6) so the left hand side may be substituted into (6) which gives (9).

$$\beta(1-q)\left[E_t[x_{t+1}]\frac{(1+\beta q^*)}{[1-\beta(1-q)]} - E_t[p_{t+1}^*]\right] = \frac{(1-q_1)}{(1-q)} E_t\left[\sum_{j=2}^{\infty} \beta^j (1-q)^j \, p_{t+1}^*\right] \tag{8}$$

$$x_t = \beta(1-q)E_t[x_{t+1}] + \frac{1-\beta(1-q)}{1+\beta q^*}\left[p_t^* + \beta q^* E_t[p_{t+1}^*]\right] \tag{9}$$

In turn we may substitute for $E_t[x_{t+1}]$ in terms of $E_t[\pi_{t+1}]$ from (B7) and $p^*=p+\gamma y+\varepsilon$ from (A11), where y is the (log) output gap and ε a shock term, to give (10) where k is defined by (11).

$$x_t = \begin{array}{l} q\sum_{r=1}^{\infty}(1-q)^{r-1}x_{t-r} + \dfrac{\beta(1+q^*)}{q(1+\beta q^*)}E_t[\pi_{t+1}] \\ +k\dfrac{(1+q^*)}{q}[\gamma y_t+\varepsilon_t+\beta q^*E_t[\gamma y_{t+1}+\varepsilon_{t+1}]] \end{array} \tag{10}$$

$$k = \frac{q[1-\beta(1-q)]}{(1-q_1)(1+\beta q^*)[1+\beta q^*(1-q)]} \tag{11}$$

In turn we may lag (10) one period to give the optimal price set at t-1 by (12).

$$x_{t-1} = \begin{array}{l} q\sum_{r=2}^{\infty}(1-q)^{r-2}x_{t-r} + \dfrac{\beta(1+q^*)}{q(1+\beta q^*)}E_{t-1}[\pi_t] \\ +k\dfrac{(1+q^*)}{q}[\gamma y_{t-1}+\varepsilon_{t-1}+\beta q^*E_{t-1}[\gamma y_t+\varepsilon_t]] \end{array} \tag{12}$$

At this point we draw on the material in Appendix B which derives the rate of inflation given the staggering structure and the prices set at different times; x_t, x_{t-1} etc. In particular (B6) may be rearranged to give (13) in which it may be seen that the two pairs of terms correspond to the left hand side minus the first term on the right hand side of (10) and (12). From (13) we can see that the origin of the Calvo special case is that with q*=0 the second pair of terms in (13) disappear so the prices set at t-1 become immaterial and $E_{t-1}[\pi_t]$, which appears in (12) but not (10), will be absent from the Phillips curve.

$$\pi_t = \frac{q}{1+q^*}[x_t - q\sum_{r=1}^{\infty}(1-q)^{r-1}x_{t-r} + q^*[x_{t-1}-q\sum_{r=2}^{\infty}(1-q)^{r-2}x_{t-r}]] \tag{13}$$

Substituting (10) and (12) into (13) gives (14) which is the Phillips curve for the generalised

Calvo-Taylor model and the key result of this section.

$$\pi_t = \begin{array}{l} \dfrac{\beta}{1+\beta q^*} E_t[\pi_{t+1}] + k(\gamma y_t + \varepsilon_t + \beta q^* E_t[\gamma y_{t+1} + \varepsilon_{t+1}]) \\ + \dfrac{\beta q^*}{1+\beta q^*} E_{t-1}[\pi_t] + kq^*(\gamma y_{t-1} + \varepsilon_{t-1} + \beta q^* E_{t-1}[\gamma y_t + \varepsilon_t]) \end{array} \qquad (14)$$

From (14) it may be seen that the absolute values of q_1 and q matter only for the parameter k given in (11) whereas q* plays a more significant role. Firstly if q*=0, the Calvo case, the whole of the second line and the last two terms of the first line disappear and (14) takes the same form as (1). If q* is positive the coefficient on $E_t[\pi_{t+1}]$ is reduced, that on $E_{t-1}[\pi_t]$ becomes larger, and the output gap and shock terms have a richer structure involving both lags and expectations over these variables which are not present in the Calvo model. It may be noted that the response of inflation in (14) to inflation expectations, output gaps and shocks has unusual properties if q* is negative but this would only arise if the probability of being able to change price decreases rather than increases with the time elapsed since the last price change. This seems implausible and we restrict attention to $0 \le q^* \le 1$.

Focusing on the role of inflation expectations in (14), Figure 1 shows the coefficients on $E_t[\pi_{t+1}]$ and $E_{t-1}[\pi_t]$ as functions of q* (by lines AA and BB respectively) with q*=0 corresponding to the Calvo model and q*=1 the Taylor model as before. The figure confirms the discussion in the introduction in that these models may be regarded as special cases of the more general model presented above with the expected inflation coefficients varying monotonically (with mild non-linearity) with q* between the two. There are no discontinuous jumps but it is clear that the particular coefficients of the Calvo and Taylor models are not robust to changes in the structure of probabilities of price changes. In a policy context, as we show in the following section, the decline in the coefficient on $E_t[B_{t+1}]$ with q* is especially significant because of its impact on the extent to which committing to future policy actions can improve the current tradeoff between inflation and the output gap. In the generalised model this coefficient varies between $\$ \,.\, 1$ if q*=0 and $\$/(1+\$) \,.\, 1/2$ if q*=1 while the coefficient on $E_{t-1}[B_t]$ varies between zero and approximately a half.

From (14) we note that q*>0, in addition to reducing the coefficient on $E_t[B_{t+1}]$, introduces the term in $E_t[y_{t+1}]$ which is a further intertemporal link in the Phillips curve though it does not offset the former effect in the policy results. More generally q*>0 gives rise to a richer structure for the effects of lagged and expected future output and shocks. In addition we note that (14) suggests that the model may give rise to observed inflation persistence (even though there is no structural persistence in the sense that lagged inflation does not appear in the Phillips curve) since the second line of (14) is equal to q* times the first line of the equivalent expression for B_{t-1}. Hence, contingent on policy choices, inflation in each period may be positively correlated with inflation in the previous and following periods. This is confirmed by the policy results of Section 3.

We also note that the generalised model shares the property of the Calvo and Taylor models individually of violating the weak form of the natural rate hypothesis in the sense that the sum of the coefficients on inflation terms on the right hand side of (14), which equals $\$(1+q^*)/(1+\$q^*)$, is less than one unless $\$=1$ though Figure 1 shows that the difference is small at least for plausible values of $\$$ close to unity (0.98 in the figure). Hence the average output gap is a function of average inflation though the relationship is very weak. Under perfect foresight (14) becomes (15) where the sum of inflation coefficients on the right hand side is simply $\$$.

$$\pi_t = \beta E_t[\pi_{t+1}] + (1+\beta q\gamma)k\gamma[q\gamma y_{t-1} + (1+\beta q\gamma^2)y_t + \beta q\gamma y_{t+1}] \qquad (15)$$

From (15) we note that under perfect foresight the generalised model reduces to the Calvo form (1) with respect to the expected inflation coefficients though the richer structure of output gaps remains. As noted above the perfect foresight Phillips curve is not applicable when analysing optimal policy responses to shocks.

Lastly, while we derived the generalised model assuming that prices are staggered with wages set flexibly ex post these roles may be reversed and the terms in expected inflation are the same as in (14). This is shown in Appendix C which uses exactly the same microfoundations as the model above while changing the staggering assumptions. Typically the Calvo model has been used only in a staggered prices-flexible wages context while the Taylor model has been used with either prices or wages staggered. Hence one may think of either of these models (defined by their assumptions about the probability of changing the staggered variable), or their generalisation above, being combined with staggered prices or staggered wages.

2. Generalised Calvo-Taylor Model: Staggered prices with wages partly set ex ante.

The generalised Calvo-Taylor model of the previous section assumed that either prices or wages were staggered, according to the (q_1,q) probability structure, whereas the other variable was set with full flexibility ex post. This naturally raises the question of what happens if there is some form of staggering or timing constraints on the setting of both variables. Clearly there are many possibilities including changes in both variables being stochastic (possibly with different probabilities) or one could be stochastic and the other set for fixed periods of time, and with each of these the variables could wholly or partly have to be set in advance rather than ex post. Exploring all of these is beyond the scope of the paper and we focus on a particular case where prices are set as in the previous section while wages are still set for a single period but with a constraint that they must be partly set in advance. We show that even with this relatively simple modification there are significant changes in the Phillips curve and optimal policy. More precisely we assume that a fraction, μ, of wages must be set in advance or on the basis of previous period information while the remaining fraction, 1-μ, are set as before. As noted above, Rotemberg and Woodford (1997) make a similar assumption with respect to price setters and the approach is also in the spirit of the original Fischer (1977) and Taylor (1979) staggering papers where wages were set ex ante as well as Barro and Gordon (1983) and Rogoff (1985) where wages are set entirely in advance. The staggering/timing assumptions of this section are also of interest because in the limit where q_1 tends to unity (so prices become flexible) and μ tends to one (all wages are set in advance) the model become the same as that in Barro and Gordon (1983) and Rogoff (1985) and the substantial literature that follows them. That having been said we do not place special emphasis on that special case and present this version of the generalised model as i) potentially realistic to the extent that prices are staggered but wages are partly set in advance of the period for which they will apply, and ii) more generally a further exploration of the possible form of the Phillips curve given different timing and staggering constraints, once again based on fully optimising microfoundations given those constraints.

From the above we assume that the aggregate or average nominal wage, W (in levels), is given by (16) where W^p is the ex post wage given by (A11) as in the previous section, and W^a the ex ante wage.[13]

$$W_t = (W_t^a)^{\mu}(W_t^p)^{1-\mu} \qquad (16)$$

For the ex ante wage we follow the approach of Rogoff (1985) which amounts to workers setting W^a in advance to satisfy the expected value (A11) which gives (17).[14]

$$W^a = \left(\frac{W}{P}\right)^{*} E_{t-1}\left[P_t\left(\frac{Y_t}{Y^{*}}\right)^{\frac{1}{\eta[1+\theta[1-\alpha(1-\frac{1}{\eta})]]}}\right] \qquad (17)$$

Using (A11), (16) and (17) the aggregate or average wage rate is given by (18) and substituting this into the optimal single period price for firm i, P_i given by (A10) gives us the log optimal single period price across all firms, p*, by (19) which may be compared with (A13) where the new constants γ_1 and γ_2 are defined in (20) and all other notation is the same as in the previous section.

$$\left(\frac{W}{P}\right)_t = \left(\frac{W}{P}\right)^{*}\left[\frac{E_{t-1}(P_t)}{P_t}\right]^{\mu}\left[\left(\frac{Y_t}{Y^{*}}\right)^{1-\mu}\left(\frac{E_{t-1}[Y_t]}{Y^{*}}\right)^{\mu}\right]^{\frac{1}{\eta[1+\theta[1-\alpha(1-\frac{1}{\eta})]]}} \qquad (18)$$

$$p_t^{*} = p_t + \gamma y_t + \varepsilon_t + \mu[\gamma_1(E_{t-1}[\pi_t]-\pi_t) + \gamma_2(E_{t-1}[y_t]-y_t)] \qquad (19)$$

[13]In common with much of the literature we ignore possible aggregation issues and treat W in (16) as the common wage level in all firms.

[14]The shocks in the model are all log-linear and all variables are log-linear in those shocks and hence arithmetic mean preserving spreads in logs and geometric mean preserving spreads in levels. Since the log of a geometric mean is the same as the arithmetic mean of a log we have the convenient result that in the model the log of an expectation is the same as an expectation of a log.

$$\gamma_1 = \frac{\alpha}{\eta[1-\alpha(1-\frac{1}{\eta})]} \quad ; \quad \gamma_2 = \frac{\gamma_1}{\eta[1+2[1-\alpha(1-\frac{1}{\varepsilon})]]} \tag{20}$$

We now summarise the derivation of the Phillips curve for this version of the generalised model. Firstly it may be noted that the new constraint on wage setting enters the derivation of Section 1 only through p* in (19) and hence (4)-(9) above remain unchanged since p* appears in general form. Substituting the new p* from (19) into (9) gives (21) as the equivalent of (10).

$$x_t = \begin{aligned} & q\Sigma_{r=1}^{\infty}(1-q)^{r-1}x_{t-r} + \frac{\beta(1+q\gamma)}{q(1+\beta q\gamma)}E_t[\pi_{t+1}] \\ & + k\frac{(1+q\gamma)}{q}\left[\begin{aligned} & \gamma y_t+\varepsilon_t+\beta q\gamma E_t[\gamma y_{t+1}+\varepsilon_{t+1}] \\ & +\gamma_1\mu(E_{t-1}[\pi_t]-\pi_t)+\gamma_2\mu(E_{t-1}[y_t]-y_t) \end{aligned}\right] \end{aligned} \tag{21}$$

We lag (21) one period to generate the equivalent expression for x_{t-1} and substitute that and (21) into (13) to give the Phillips curve for this model by (22).

$$\pi_t = \begin{aligned} & \left[\frac{\beta}{(1+\beta q\gamma)(1+k\gamma_1\mu)}\right]E_t[\pi_{t+1}] + \left[\frac{\beta q\gamma+(1+\beta q\gamma)k\gamma_1\mu}{(1+\beta q\gamma)(1+k\gamma_1\mu)}\right]E_{t-1}[\pi_t] \\ & + \frac{kq\gamma\gamma_1\mu}{1+k\gamma_1\mu}(E_{t-2}[\pi_{t-1}]-\pi_{t-1}) \\ & + \frac{k}{1+k\gamma_1\mu}[\gamma y_t+\varepsilon_t+\beta q\gamma E_t[\gamma y_{t+1}+\varepsilon_{t+1}]+\gamma_2\mu(E_{t-1}[y_t]-y_t)] \\ & \frac{kq\gamma}{1+k\gamma_1\mu}[\gamma y_{t-1}+\varepsilon_{t-1}+\beta q\gamma E_{t-1}[\gamma y_t+\varepsilon_t]+\gamma_2\mu(E_{t-2}[y_{t-1}]-y_{t-1})] \end{aligned} \tag{22}$$

We briefly note the properties of (22) compared with (14): i) (22) reduces to (14) if μ=0, which simply follows from the definition of μ; ii) the perfect foresight version of (22) is the same as the perfect foresight version of (14) given by (15), which follows by inspection of (19) given that expectation errors are zero under perfect foresight (intuitively, perfect foresight implies that the distinction between setting a variable ex ante and ex post disappears); iii) more generally if wages are partly set in advance (μ>0) the coefficient on $E_t[B_{t+1}]$ in the Phillips curve (22) is smaller than in (14) and that on $E_{t-1}[B_t]$ is larger; iv) a special case of this is that if μ and q_1 tend to unity (so prices are flexible, which implies that k becomes large, and all wages are set ex ante) the coefficient on $E_t[B_{t+1}]$ tends to zero and that on $E_{t-1}[B_t]$ tends to unity (thus giving a "Barro-Gordon-Rogoff" form to inflation expectations in the Phillips curve); v) the ex ante setting of some wages results in the expectation error terms in the second, third and fourth lines of (22); and vi) (22) also violates the natural rate hypothesis though once again the sum of inflation coefficients on the right hand side is close to unity (it is also increasing in μ).

3. Optimal Monetary Policy in the Generalised Calvo-Taylor Model

We analyse optimal monetary policy both with commitment and under discretion in the generalised Calvo-Taylor model of Section 1. In particular we focus on the extent to which the reduction in the coefficient on $E_t[B_{t+1}]$ below $\$$, its value in the Calvo model, if q*>0 affects the degree to which optimal policy commits to future lower inflation in order to influence the current inflation-output tradeoff. With a smaller coefficient on forward looking inflation in the Phillips curve we show that the optimal use of this mechanism is reduced, an immediate consequence being that optimal policy no longer implies price level targeting if q*>0. Hence we demonstrate that the value of q*, and thus the nature of the Phillips curve (14), has important implications for optimal monetary policy. As discussed in the introduction we make no claim that any particular value of q* is correct, suggesting instead, in the spirit of the contributions to Taylor (1999), that monetary policy recommendations should ideally be robust to different coefficients in the Phillips curve (which in this model corresponds to different values of q*).

Commitment

We first derive the optimal timeless perspective monetary policy rule when commitment is feasible by analysing the policy maker's minimisation of the (standard) loss function (23) subject to the Phillips curve constraint (14). In (23) λ is the relative weight on output gap fluctuations and for simplicity we assume that the target inflation rate is zero. The latter assumption does not affect the results except in so far as price level targeting would become targeting a price level trend. We also assume for simplicity that there is no serial correlation in the supply shocks and that the policy maker may be thought of as setting output directly.

$$L = \sum_{t=0}^{\infty} \beta^t [\lambda y_t^2 + \pi_t^2] \tag{23}$$

We proceed by first examining the constraints on policy imposed by the Phillips curve (14). We conjecture that inflation and output under the optimal rule will be linear in the current and past values of the shock variable and given by (24) and (25) respectively where the coefficients c_1, d_1, etc are to be determined.

$$\pi_t = c_1 \varepsilon_t + c_2 \varepsilon_{t-1} + c_3 \varepsilon_{t-2} + c_4 \varepsilon_{t-3} + \ldots \tag{24}$$

$$y_t = d_1 \varepsilon_t + d_2 \varepsilon_{t-1} + d_3 \varepsilon_{t-2} + d_4 \varepsilon_{t-3} + \ldots \tag{25}$$

Substituting (24) and (25) into (14) gives the Phillips curve constraint in terms of the history of shocks by (26).

$$0\ '\ \begin{aligned} &,_t[k\&c_1\%\frac{\$c_2}{1\%\$q^{(}}\%k(\,[d_1\%\$q^{(}d_2]] \\ &\%,_{t\&1}[kq^{(}\&\frac{(c_2\&\$c_3)}{1\%\$q^{(}}\%k(\,[q^{(}d_1\%(1\%\$q^{(2})d_2\%\$q^{(}d_3]] \\ &\%,_{t\&2}[\&\frac{(c_3\&\$c_4)}{1\%\$q^{(}}\%k(\,[q^{(}d_2\%(1\%\$q^{(2})d_3\%\$q^{(}d_4]] \\ &\%,_{t\&3}[\&\frac{(c_4\&\$c_5)}{1\%\$q^{(}}\%k(\,[q^{(}d_3\%(1\%\$q^{(2})d_4\%\$q^{(}d_5]] \\ &\%\ \ldots \end{aligned} \qquad (26)$$

The structure of (26) repeats from $,_{t\text{-}2}$ across earlier shocks which imposes the constraint that each value of the coefficients in (24) and (25) from c_4 and d_3 onwards respectively must differ from the previous coefficient by a common multiplicative factor which we denote * such that c_4=*c_3, c_5=*c_4, d_3=*d_2 etc. Substituting this constraint into (26) gives (27) where the summary parameter, A, is 1+\$q*(q*+*). The three square bracketed expressions to the right of each line in (27) must all equal zero such that (27) as a whole equals zero given that the , terms may take non-zero values. Hence the Phillips curve (14) implies three separate constraints on the choice of the coefficients in (24) and (25). The latter may also be expressed by (28) and (29). The second and third lines of (27) also imply that as q* (and thus the kq* term of the second line) tends to zero, c_3 must tend to *c_2 and d_2 to *d_1.

$$0\ '\ \begin{aligned} &,_t[k\&c_1\%\frac{\$c_2}{1\%\$q^{(}}\%k(\,[d_1\%\$q^{(}d_2]] \\ &\%,_{t\&1}[kq^{(}\&\frac{(c_2\&\$c_3)}{1\%\$q(}\%k(\,[q^{(}d_1\%Ad_2]] \\ &\%[\,,_{t\&2}\%*\,,_{t\&3}\%*^2\,,_{t\&4}\%\ldots][\&\frac{c_3(1\&\$*)}{1\%\$q^{(}}\%k(\,d_2(q^{(}\%*A)] \end{aligned} \qquad (27)$$

$$\mathrm{B}_t \; ' \; c_1 ,_t \% c_2 ,_{t\&1} \% c_3 (,_{t\&2} \% * ,_{t\&3} \% *^2 ,_{t\&4} \% *^3 ,_{t\&5} \% ...) \qquad (28)$$

$$y_t \; ' \; d_1 ,_t \% d_2 (,_{t\&1} \% * ,_{t\&2} \% *^2 ,_{t\&3} \% *^3 ,_{t\&4} \% ...) \qquad (29)$$

Having analysed the constraint we derive optimal policy (the values of c_1, c_2, c_3, d_1, d_2 and * by maximising the Lagrangean (30) where B_t and y_t are given by (28) and (29) and the summary term, C, is simply the right hand side of (27). The multiplier, N_t is conjectured to take the form (31) such that it has three independent parameters to match the three constraints implicit in (27) and a repeating structure comparable to B_t and y_t.

$$Max \;\; E_0 \mathrm{E}^4_{t\,'\,0} \$^t [\& \frac{1}{2} (8 y_t^{\,2} \% \mathrm{B}_t^2) \% \mathrm{N}_t C] \qquad (30)$$

$$\mathrm{N}_t \; ' \; e_1 ,_t \% e_2 ,_{t\&1} \% e_3 (,_{t\&2} \% * ,_{t\&3} \% *^2 ,_{t\&4} \% *^3 ,_{t\&5} \% ...) \qquad (31)$$

We partially differentiate (30) with respect to c_1, c_2, c_3, d_1 and d_2 and take the expectation of each (using the assumption of uncorrelated shocks such that $E[,_i^{\,2}]=\mathrm{F}^2$ and $E[,_i ,_j]=0$) to give the first order conditions (32)-(36).

$$c_1 \; ' \; \& e_1 \qquad (32)$$

$$c_2 \; ' \; \frac{e_1 \& e_2}{1 \% \$ q^{\,(}} \qquad (33)$$

$$c_3 \; ' \; \frac{e_2 (1 \& \$ *^2) \& e_3 (1 \& \$ *)}{1 \% \$ q^{\,(}} \qquad (34)$$

$$d_1 = \frac{k\gamma}{\lambda}(e_1 + \beta q^* e_2) \tag{35}$$

$$d_2 = \frac{k\gamma}{\lambda}[(1-\beta\delta^2)(q^* e_1 + \rho e_2) + \beta(q^* + \delta\rho)e_3] \tag{36}$$

We substitute (32)-(36) into the three square bracketed expressions in (27), set each to zero and solve the resulting simultaneous equations in e_1, e_2 and e_3 subject to the constraint discussed above that c_3 tends to δc_2 which implicitly determines δ by (37).[15]

$$\delta(1-\delta)(1-\beta\delta) - \frac{k^2\gamma^2}{\lambda}(1+\beta q^*)^2(q^* + \delta\rho)^2 = 0 \tag{37}$$

The results for the coefficients in (31) are given by (38)-(40) where the summary parameters B and D are given by (41)-(42).

$$e_1 = -\frac{B}{D}[q^*(q^* + \delta\rho) + \delta(1+q^*)(1+\beta q^*)] \tag{38}$$

$$e_2 = -\frac{B}{D}[q^*(q^* + \delta\rho)(\delta + q^* + \rho) + \delta^2(1+q^*)(1+\beta q^*)] \tag{39}$$

$$e_3 = -\frac{B}{D}[\delta^2 q^*(q^* + \delta\rho) + q^*(q^* + \rho)(q^* + \delta^2\rho) + \delta^3(1+q^*)(1+\beta q^*)] \tag{40}$$

$$B = k(1+\beta q^*)^3(q^* + \delta\rho)^2 \tag{41}$$

[15] This expression may also be obtained from a simple perfect foresight optimisation of (30) in π and y directly with no shocks after ε_{t-2}. If q*=0 (37) reduces to the equivalent expression in Clarida et. al. (1999). In the simulations below we assume values for k, γ and λ such that (37) has a solution with $0 \le \delta \le 1$. For some values of q* (37) has two solutions within this range in which case we choose the solution continuous in q* with that obtained when q*=0.

$$D \;\text{'}\; \frac{[(q^{(}\%{*}A)(q^{(}\%{*})[(1\%\$q^{(})^{2}\%\$(1\&{*})]\%{*}A(1\&{*})(1\&\${*})]}{.[(q^{(}\%{*}A)^{2}[1\%\$(1\&{*})]\%(1\&{*})(1\&\${*})[{*}A^{2}\&\$q^{(2}(1\&{*})]] \\ \%q^{(2}(1\&{*})(1\&\${*})[\&\$(q^{(}\%{*}A)^{2}\%\$q^{(}{*}(1\&{*})(1\&\${*})(1\%\$q^{(}\%A)]} \qquad (42)$$

D is expressed in compact form but may readily be shown to be positive such that B/D is positive and thus e_1, e_4 and e_5 are all negative. If q*=0, e_2=*e_1 and e_3=*$^2e_1$ which, together with all the results when q*=0, corresponds to the results of Clarida et. al. (1999) and McCallum and Nelson (2000).

From (38)-(42) the coefficients of the reduced forms (28) and (29) and thus inflation and output are straightforwardly derived from (32)-(36). We first present an analytic result showing that the cumulative effect on the price level of optimal policy following a shock is strictly positive if q* is strictly positive which contrasts with the stationarity of the price level under an optimal rule in the Calvo model where q*=0 shown by Clarida et. al. (1999). To show this we assume a single shock at some time s, $*_s$, and note that from (28) the sum of the changes in inflation resulting from this shock, which corresponds to the cumulative effect on the price level, is given simply by (43).

$$p_4\&p_{s\&1} \;\text{'}\; \mathrm{E}^{4}_{t\text{'}s}\mathrm{B}_t \;\text{'}\; c_1\%c_2\%\frac{c_3}{1\&{*}} \qquad (43)$$

Using the results above we may substitute for the c parameters in which case (43) may be shown to equal (44) which is zero if q* is zero but strictly positive (negative) for an inflation increasing (decreasing) shock if q* is strictly positive.

$$p_4\&p_{s\&1} \;\text{'}\; ,_s[\frac{B(1\%\$q^{(})}{D}q^{(}(1\&{*})(1\%q^{(})(q^{(}\%\${*})] \;\$\; 0 \;\; as \;\; q^{(} \;\$\; 0 \qquad (44)$$

We show the more general implications of the generalised Calvo-Taylor model derived above for optimal policy graphically in Figures 2-4. These show the response of inflation, output and the price level under the optimal rule to a single shock (for illustrative purposes) in period 1. The simulations assume for illustration that there are no further shocks and that inflation and output (and expectations of their future values) are all zero prior to the shock. Assumed parameter values are α=0.67, β=0.98, η=6, θ=0.5, λ=0.5, q_1=0.5-q*/2 and q=0.5+q*/2. We do not specify a value for the particular shock modelled but this has a simple multiplicative effect on all the variables in all time periods and hence does not affect the comparisons between them. For this reason we do not show a numerical scale on the vertical axes.

Figure 2 shows the cumulative effect on the price level over time of the single shock in period 1 under the optimal rule for q*=0, 0.5, 1. This confirms the result above that for q*>0 the optimal rule does not correspond to targeting the price level whereas the price level is stationary if q*=0. It also shows that the long run impact of a shock on the price level is convex in q*.

Figure 3 shows inflation rates over time following the shock. It may be seen that when q*>0 inflation the period after the shock tends to be positive. This reflects two factors, first the shock in period 1 also affects the Phillips curve in period 2 through the $q^*\varepsilon_{t-1}$ term in (14), and second the smaller coefficient on $E_t[\pi_{t+1}]$ in the Phillips curve with q*>0 implies less gain from the rule committing to a low inflation rate the period after the shock. The first of these factors matters for the optimal inflation path but is not decisive for the long run price level remaining above its initial value. If we imposed this "shock" in period 2 in a Calvo model the price level would still be stationary (since it is stationary in relation to a single shock and the effects of more than one shock are additive). In period 3 the effect of the $E_t[\pi_{t+1}]$ term may be seen in that the strongly negative inflation rates when q*>0 will improve the inflation-output tradeoff in period 2. This linkage between periods 2 and 3 is not affected by the reduced coefficient on forward looking inflation in (14) because after period 1 the response to the period 1 shock is completely predictable and the perfect foresight Phillips curve (15) has a coefficient on forward looking inflation equal to β, as in the Calvo case, for any q*. Figure 4 shows the output gap under the optimal rule. The time paths here are similar but the deviation of the output gap from zero is larger the larger is q*. This partly reflects the $q^*\varepsilon_{t-1}$ term in (14) such that the total impact of the period 1 shock is increasing in q*.

<u>Discretion</u>

Under discretion we continue to assume that the policy maker minimises the loss function (23) subject to the Phillips Curve constraint (14) but with the additional constraint that commitment is not possible. This means that expectations already formed and past values of variables are taken as given at the time that policy choices are made though the policy maker may and should take into account the effect of current choices on future choices subject to that constraint. In effect the policy maker may take advantage of reduced form intertemporal relationships that emerge from optimal policy making (which is important given the intertemporal nature of the Phillips curve with q*>0) but cannot optimise those relationships directly.

To derive optimal policy under discretion we form the Lagrangean (44) where ω_t is the multiplier for the discretion case.

$$L = \sum_{t=0}^{\infty} \beta^t \Big[-\frac{1}{2}(\lambda y_t^2 + \pi_t^2) + \mu_t \Big[-\pi_t + \frac{\beta}{1+\beta q^*} E_t[\pi_{t+1}] + \frac{\beta q^*}{1+\beta q^*} E_{t-1}[\pi_t] + k\varepsilon_t + kq^*\varepsilon_{t-1} + k\big([q^* y_{t-1} + \beta q^{*2} E_{t-1}[y_t] + y_t + \beta q^* E_t[y_{t+1}]\big] \Big] \Big] \tag{45}$$

Given the presence of y_{t-1}, ε_t and ε_{t-1} in the Phillips curve we conjecture the reduced form solutions for inflation and output given by (46) and (47) such that differentiating (45) with respect to output will take account of the reduced form ϕ parameters, including their effect on expectations, but without the policy maker being able to optimise their values since this would require a commitment to respond to past values.

$$\pi_t = \phi_\pi y_{t-1} + a_1 \varepsilon_t + a_2 \varepsilon_{t-1} \tag{46}$$

$$y_t = \phi y_{t-1} + b_1 \varepsilon_t + b_2 \varepsilon_{t-1} \tag{47}$$

From (45)-(47) we find the first order conditions for the maximisation of (45) shown by (48) and (49).

$$\pi_t = -\mu_t \tag{48}$$

$$y_t = \frac{1}{\lambda}\Big[\frac{\beta\phi_\pi}{1+\beta q^*} + k\big((1+\beta q^*\phi)\big)\Big]\big[\mu_t + \beta q^* E_t[\mu_{t+1}]\big] \tag{49}$$

Substituting the first order conditions into (14) we find that ϕ is given by (50) and μ_t by (51) where coefficients and constants are shown by (52)-(54).

$$0 = \rho(1-\beta\rho)^2 + \frac{k^2\gamma^2}{\lambda}(1+\beta q^*)^2(q^*+\rho)(1+\beta q^*\rho)^3 \tag{50}$$

$$\omega_t = e_1\varepsilon_t + e_2(\varepsilon_{t-1}+\rho\varepsilon_{t-2}+\rho^2\varepsilon_{t-3}+\ldots) \tag{51}$$

$$e_1 = \frac{-k}{E}\left[\frac{1-\beta\rho+\beta q^*}{1+\beta q^*} + \frac{k^2\gamma^2}{\lambda(1-\beta\rho)}(1+\beta q^*\rho)^3(1+\beta q^*)\right] \tag{52}$$

$$e_2 = \frac{-kq^*}{E} \tag{53}$$

$$E = \frac{\dfrac{1-\beta\rho}{1+\beta q^*} + \left[\dfrac{k^2\gamma^2}{\lambda(1-\beta\rho)}(1+\beta q^*\rho)^3(1+\beta q^*)\right]^2}{\dfrac{k^2\gamma^2}{\lambda(1-\beta\rho)}(1+\beta q^*\rho)(1+\beta q^*)\left[(1+\beta q^*\rho)^2+\beta q^{*2}(2+\beta q^*\rho)+\dfrac{1-\beta\rho+\beta q^*}{1+\beta q^*}\right]} \tag{54}$$

Having established the process for the multiplier we may substitute these results into the first order conditions above to give inflation and output explicitly. We show these results graphically in Figure 5 below which compares rule and discretion outcomes for inflation and output for q*=0, 0.5, 1. The top pair of figures repeats the standard Calvo results (see Clarida et. al., 1999) that optimal policy under discretion simply responds to the current value of the shock variable with inflation and the output gap returning to zero immediately if no further shock occurs the following period. In this case $\rho=0$. Once q* is greater than zero, y_{t-1} and ε_{t-1} appear in the Phillips curve such that ρ is no longer zero (in fact it becomes negative) and policy both responds to ε_{t-1} and also the current choice of output, y_t, determines the value of "y_{t-1}" the following period. The latter effect is small, however, since in period 3 when the effect of the period 1 shock is no longer present, optimal discretionary choices are close to zero. Hence while the outcomes under discretion are fairly close to the rule in period 1 when the shock occurs the major difference lies in period 3 when the rule can commit to negative inflation (which benefits the period 2 outcome also) while discretion achieves only marginally negative inflation, in turn worsening the period 2 outcome.

Figures 6 and 7 give results for the effect of optimal policy in each case on the expected per period value of the loss function. As expected the loss under the rule is less than that under discretion but both of them, and the relative gap between them shown by Figure 7, increase with q*. This follows from the fact that an increase in q* effectively raises the total variance of the shocks hitting the economy since a shock in one period has an additional effect the following period with weight q*.

Lastly, Figure 8 examines the reduced form persistence properties of inflation and output under discretion, shown by the simple correlation coefficient between neighbouring values. These are zero when q*=0 (since the Calvo model has no intertemporal dimension under discretion) but rise significantly above zero as q* increases. It should be emphasised that we do not place a structural interpretation on these values, especially that for inflation since B_{t-1} is not present in the Phillips curve (14), but they show that observed inflation and output persistence can arise from the generalised Calvo-Taylor model without serial correlation in the shock process.

3. Conclusion

This paper has analysed the microfoundations of the New Keynesian Phillips Curve, exploring the reason for the differences between the Calvo and Taylor models when prices are staggered. It presented a generalised model which nested these as special cases by means of allowing the probability of firms changing price to vary between the period immediately after a price change and subsequent periods. While this change only affects one period, and is only one of many possible changes to the staggering structures of these models that could be made, it shows that the coefficients on expected inflation and the structure of the output and shock terms in the Phillips curve vary significantly with the difference between these two probabilities.

The model clarifies the source of the different predictions for the Phillips curve in an otherwise common framework, showing that they result solely from differences in staggering structures given optimising behaviour by agents. While not itself giving a unique prediction of the appropriate Phillips curve coefficients to use in policy modelling the paper nevertheless has a strong conclusion that we should be wary of policy results that rest sensitively on a particular staggering assumption or, equivalently, a particular coefficient on forward looking inflation in the Phillips curve. In particular i) it was shown that the price level targeting result of Clarida, Gali and Gertler (1999) is not robust to changes in the structure of staggering away from Calvo pricing; and ii) that the generalised model may contribute to our understanding of observed persistence in inflation (and output) even in the absence of a structural term in lagged inflation in the Phillips Curve.

Figure 1: Inflation Expectations Coefficients in the Generalised Calvo-Taylor Model

Simulation of (13) with $\$=0.98$; "A-A" is the coefficient on $E_t[B_{t+1}]$, "B-B" is the coefficient on $E_{t-1}[B_t]$, and their combined value is shown by "Sum".

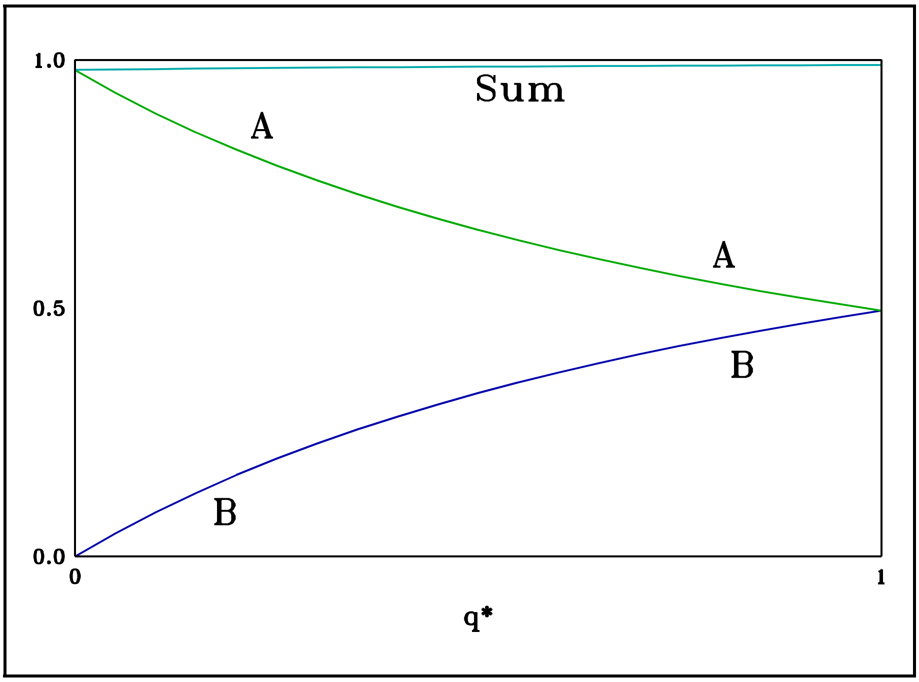


Figure 2: Price Level Under the Optimal Rule (Single Shock in Period 1)

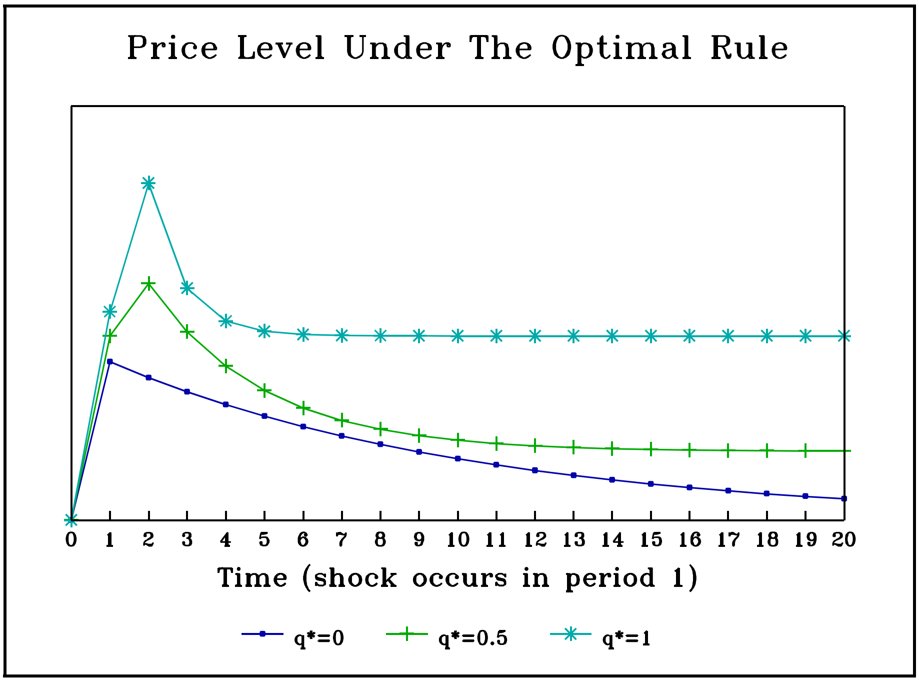


Figure 3: Inflation Under the Optimal Rule (Single Shock in Period 1)

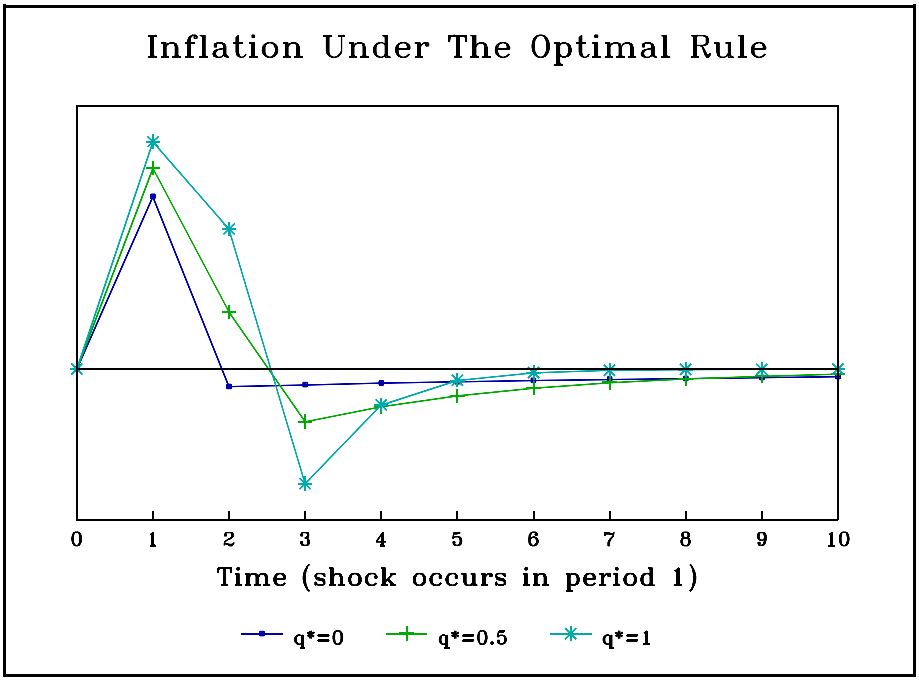


Figure 4: Output Gap Under the Optimal Rule (Single Shock in Period 1)

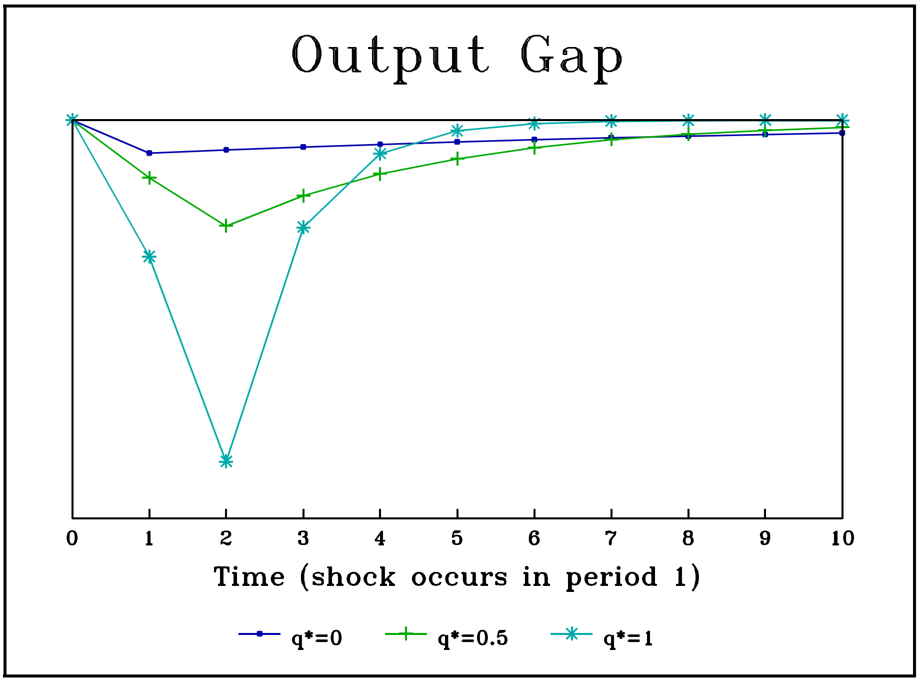


Figure 5: Rule and Discretion Outcomes Compared (Single Shock in Period 1)

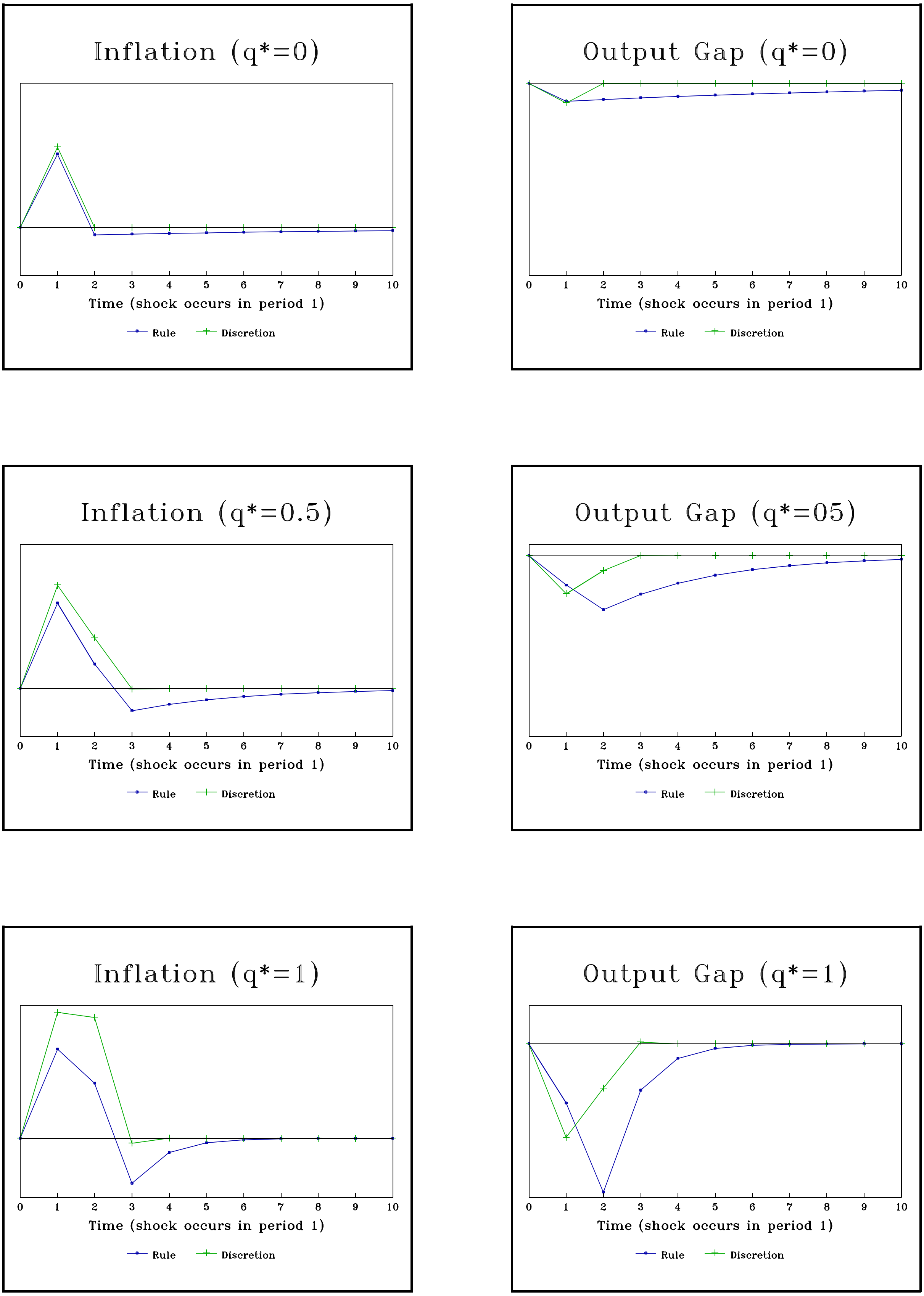


Figure 6: Expected Level of Per Period Loss Under Rule and Discretion

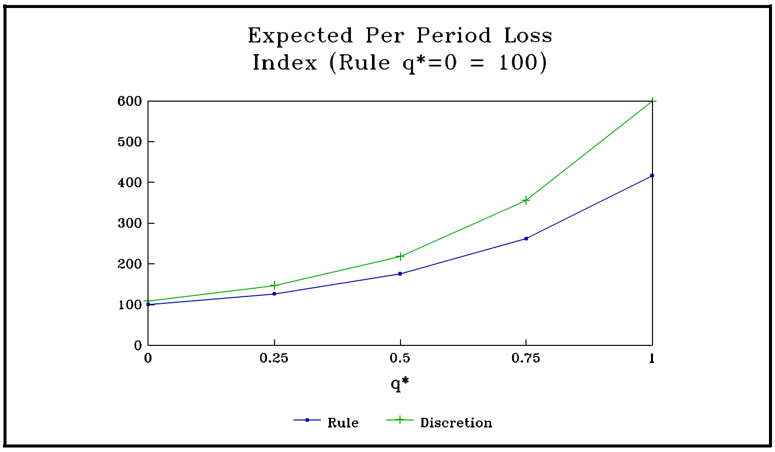


Figure 7: Expected Relative Loss Under Rule and Discretion

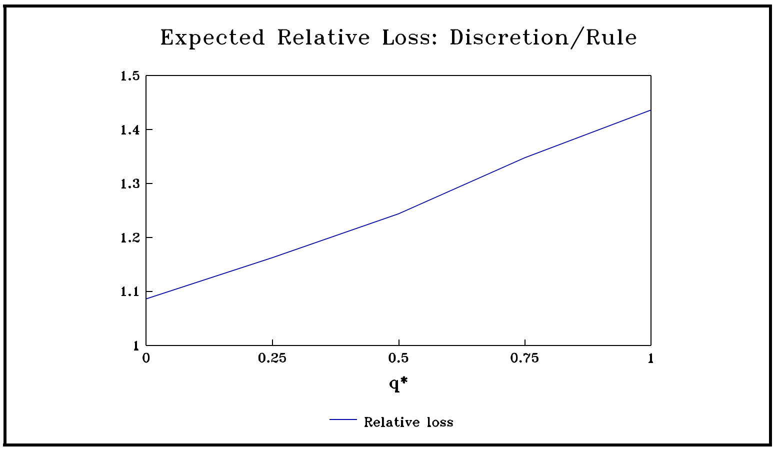
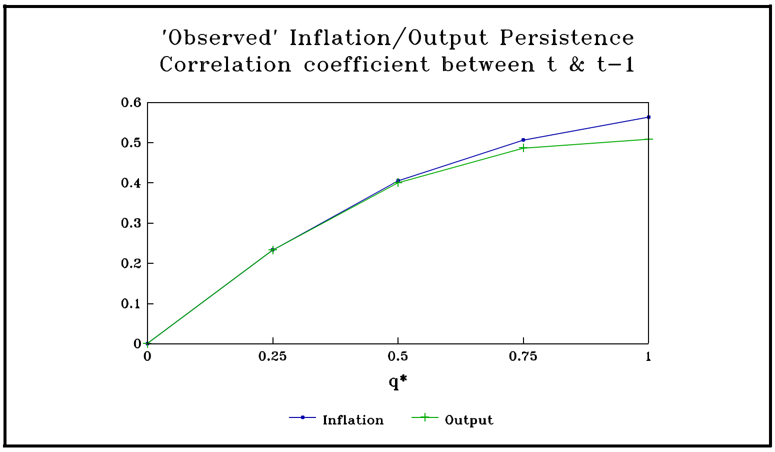


Figure 8: Simple Correlation Coefficient Between B_t, B_{t-1} and y_t, y_{t-1} Under Discretion



Appendix A: Microfoundations of Optimal Price and Wage Setting

We derive expressions for the prices and wages that would be set each period in a flexible price/wage environment in order to generate 'ideal' prices and wages per period which form part of the derivation of optimal price (later wage) setting once staggering constraints are imposed. The microfoundations of these choices are standard. We consider a large number of symmetric, monopolistically competitive firms, indexed by i, each with production function (A1), where Y_i is firm output, K_i the firm's capital stock which we hold constant and L_i firm level employment. Any multiplicative constant that may be present in (A1) is normalised to unity for convenience and without loss of generality. All expressions in this appendix refer to a single period and hence for simplicity we do not include time subscripts.

$$Y_i = K_i^{1-\alpha} L_i^{\alpha} \qquad \text{(A1)}$$

Each firm also faces the demand curve (A2) where P_i is the firm's price, P the general price level (defined as the weighted geometric mean of firm prices with weights summing to unity and equal to the proportion of all firms with each particular price), η the common price elasticity of demand (defined such that $\eta>0$) and Y_{di} an index of aggregate demand per firm.

$$Y_i = \left(\frac{P_i}{P}\right)^{-\eta} Y_{di} \qquad \text{(A2)}$$

We also make use of the notation W for the common nominal wage which is exogenous to firms individually, c_K for the per period cost of capital (which plays no part in the analysis since capital is fixed), and R_i for firm profits. Profits are given by $R_i=P_iY_i-WL_i-c_K$ in terms of the three variables endogenous to the firm, P_i, Y_i and L_i. For given Y_{di} and P the choice of any of these three implies the other two through (A1) and (A2) and we substitute from those expressions for

Y_i and L_i to give profits in terms of P_i by (A3).

$$R_i = P[(\frac{P_i}{P})^{1-\eta} Y_{di} - K_i^{-\frac{(1-\alpha)}{\alpha}} (\frac{W}{P})(\frac{P_i}{P})^{-\frac{\eta}{\alpha}} Y_{di}^{\frac{1}{\alpha}}] - c_K K_i \qquad \text{(A3)}$$

Differentiating (A3) with respect to P_i gives the first order condition for price, (A4), which may be substituted into (1) and (2) to give optimal employment by (A5) and output by (A6). The second order condition for profit maximisation may readily be shown to be satisfied.

$$P_i = P[\frac{Y_{di}^{1-\alpha}(\frac{W}{P})^{\alpha}}{K_i^{1-\alpha}[\alpha(1-\frac{1}{\eta})]^{\alpha}}]^{\frac{1}{\eta[1-\alpha(1-\frac{1}{\eta})]}} \qquad \text{(A4)}$$

$$L_i = [\frac{\alpha(1-\frac{1}{\eta})K_i^{(1-\alpha)(1-\frac{1}{\eta})} Y_{di}^{\frac{1}{\eta}}}{\frac{W}{P}}]^{\frac{1}{1-\alpha(1-\frac{1}{\eta})}} \qquad \text{(A5)}$$

$$Y_i = [\frac{\alpha(1-\frac{1}{\eta})K_i^{\frac{1-\alpha}{\alpha}} Y_{di}^{\frac{1}{\eta}}}{\frac{W}{P}}]^{\frac{\alpha}{1-\alpha(1-\frac{1}{\eta})}} \qquad \text{(A6)}$$

In (A4)-(A6) the powers on the firm level quantity variables, L_i, K_i and Y_{di} are such that we may multiply each of these by the number of firms which then cancels such that the P_i in (A4) may be expressed as a function of aggregate demand, Y_d, and the aggregate capital stock and (A5) and (A6) give aggregate employment and output simply by dropping the i subscripts. From this point K_i may be normalised to unity. P_i in (A4) may also be shown to be equal to nominal marginal cost divided by $(1-1/\eta)$ but we keep the roles of output and the real wage separate for clarity.

We turn to wage setting behaviour, assuming that wages are set competitively by many small groups of workers (who by symmetry set the same wage) whose preferences may be summarised by the aggregate labour supply curve $L_s=(W/P)^2$ where without loss of generality a possible multiplicative constant is normalised to unity. Equating labour supply with aggregate labour demand from (A5) without i subscripts gives the equilibrium real wage by (A7). While we think of workers setting the nominal wage we express outcomes in terms of the real wage for convenience, noting that with contemporaneous wage setting rational workers will have full information about the real wage that will result from any given nominal wage. Using the labour supply curve and (A1) equilibrium employment and output are given by (A8) and (A9).

$$\frac{W}{P} \ ' \ [''(1\&\frac{1}{0})Y^{\frac{1}{0}}]^{\frac{1}{1\%2[1\&''(1\&\frac{1}{0})]}} \qquad (A7)$$

$$L \ ' \ [''(1\&\frac{1}{0})]^{\frac{2}{1\%2(1\&'')}} \qquad (A8)$$

$$Y \ ' \ [''(1\&\frac{1}{0})]^{\frac{''2}{1\%2(1\&'')}} \qquad (A9)$$

Given that we have assumed complete within period price and wage flexibility and not yet introduced shocks (A7)-(A9) may be interpreted as flexible wage-price natural rates. Denoting these with a "*" we may re-express (A4) and (A7), each with their right hand side variables at their natural rates, compactly in terms of deviations from natural rates by (A10) and (A11).

$$P_i \ ' \ P[(\frac{Y}{Y^{(}})^{1\&''}(\frac{\frac{W}{P}}{(\frac{W}{P})^{(}})^{''}]^{\frac{1}{0[1\&''(1\&\frac{1}{0})]}} \qquad (A10)$$

$$\frac{W}{P} \; ' \; (\frac{W}{P})^{(} \; (\frac{Y}{Y^{(}})^{\frac{1}{0[1\%2[1\&"(1\&\frac{1}{0})]}} \qquad \text{(A11)}$$

We make further use of (A11) when we consider staggering of wages below but for the time being the core version of the model assumes complete wage flexibility while prices are staggered so (A11) may simply be substituted into (A10) which gives (A12) as the ideal single period price which would be set by an individual firm in the absence of staggering constraints.

$$P_i \; ' \; P(\frac{Y}{Y^{(}})^{\frac{1\%2(1\&")}{0[1\%2[1\&"(1\&\frac{1}{0})]}} \qquad \text{(A12)}$$

As a final step (see Walsh, 1998 p.219) we take logs of (A12) and assume a log linear shock to price setting (which could also arise from wage setting through (A11) substituted into (A10)), , , to give (A13) as the single period ideal price in logs which we denote p* (without an i subscript since it is symmetric across all firms). We also add time subscripts and y refers to the log of (Y/Y*), the output gap.

$$p_t(\; ' \; p_t \; \% \; (y_t \; \% \; ,_t \quad ; \quad (\; ' \; \frac{1\%2(1\&")}{0[1\%2[1\&"(1\&\frac{1}{0})]} \qquad \text{(A13)}$$

Appendix B: Inflation Given Optimal Prices or Wages

We first derive the aggregate inflation rate for given individual staggered prices set by firms for use in the derivation of the generalised Calvo-Taylor Phillips curve in Section 1. The new price set by firms in period t that are able to change their price at that time is x_t, and the probability of being able to change price again the following period is q_1 and, assuming that a new price has not already been set, q each period thereafter. We derive the distribution of prices existing in each period, distinguished by the time since they were set, on the assumption that the distribution is in its ergodic stationary state. Given that distribution the derivation of the inflation rate in terms of prices set at different times is straightforward.

We start by assuming that at time t-1 there is a given (for the time being unknown) proportion of firms, s, that have changed their price at t-1 with the remaining prices having been set at time t-r being distributed with (unknown) weights $(1\text{-}s)\omega_r$ such that p_{t-1} is given by (B1) where $\Sigma\omega=1$.

$$p_{t-1} = s x_{t-1} + (1-s)\Sigma_{r=2}^{\infty} \omega_r x_{t-r} \tag{B1}$$

Moving forward one period to time t, these prices will evolve as follows. Considering the first term in (B1), the probability of these prices changing again at time t is q_1 and the probability of remaining the same, $1\text{-}q_1$. Given the assumed large number of firms these probabilities translate into proportions and hence at time t these prices will become x_t with weight (ie. their proportion of all the prices that will exist at time t) $q_1 s$ and remain at x_{t-1} with weight $(1\text{-}q_1)s$. Of the prices in the second term in (B1), the probability of their changing is q and hence these prices will either change into x_t (with weight (1-s)q, noting that $\Sigma\omega=1$) or remain at x_{t-r} (with weights $(1\text{-}q)(1\text{-}s)\omega_r$ respectively). Hence p_t is given by (B2).

$$p_t = [q_1 s + q(1-s)]x_t + (1-q_1)s x_{t-1} + (1-q)(1-s)\sum_{r=2}^{\infty}\omega_r x_{t-r} \tag{B2}$$

Making use of the notation $q-q_1=q^*$ we first equate the proportions of newly changed prices at t-1, s in (B1), and t, $q_1s+(1-s)q$ in (B2), which implies that $s=q/(1+q^*)$. Substituting for s in (B1) and (B2) gives (B3) and (B4) for p_{t-1} and p_t.

$$p_{t-1} = \frac{q x_{t-1} + (1-q_1)\sum_{r=2}^{\infty}\omega_r x_{t-r}}{1+q^*} \tag{B3}$$

$$p_t = \frac{q x_t + q(1-q_1)x_{t-1} + (1-q_1)(1-q)\sum_{r=2}^{\infty}\omega_r x_{t-r}}{1+q^*} \tag{B4}$$

Equating the proportions of prices set 1, 2, 3 etc. periods before in (B3) and (B4) gives $\omega_1=q$ and $\omega_r=q(1-q)^{r-2}$ for $r\geq 2$. Substituting these ω values into (B4) gives (B5) and subtracting the equivalent expression for p_{t-1} gives inflation, π_t by (B6).

$$p_t = \frac{q}{1+q^*}[x_t + (1-q_1)\sum_{r=1}^{\infty}(1-q)^{r-1}x_{t-r}] \tag{B5}$$

$$\pi_t = \frac{q}{1+q^*}[x_t - q_1 x_{t-1} - q(1-q_1)\sum_{r=2}^{\infty}(1-q)^{r-2}x_{t-r}] \tag{B6}$$

In Section 1 (B6) is re-expressed in a convenient form and we also make use of (B7) which is derived from shifting (B6) one period forward and take expectations at t.

$$E_t[\pi_{t+1}] = \frac{q}{1+q^*}(E_t[x_{t+1}] - q_1 x_t - q(1-q_1)\sum_{r=1}^{\infty}(1-q)^{r-1}x_{t-r}) \tag{B7}$$

Appendix C: Staggered wages with flexible prices

We turn to the rate of inflation in the generalised Calvo-Taylor model of Section 2 where wages are staggered and prices are set flexibly period by period ex post. Workers are assumed to face the same probabilities over the ability to change their wages as firms did over their prices in the price setting version of the model set out in Section 1. Since the resulting structure of this version of the model is very similar we give a brief treatment. Firstly, from (A10) with P_i=P (given that all price setting is at the same time ex post) the log price is given by (C1).

$$p_t = w_t + \frac{(1-\alpha)}{\alpha} y_t - Ln[(W/P)^*] + \varepsilon_t \qquad \text{(C1)}$$

From (C1) the rate of price inflation, π, in terms of nominal wage inflation π^w is given by (C2).

$$\pi_t = \pi_t^w + \frac{(1-\alpha)}{\alpha}(y_t - y_{t-1}) + \varepsilon_t - \varepsilon_{t-1} \qquad \text{(C2)}$$

From (A11) the ideal wage that workers would set each period in the absence of any constraints on changing wages again, w*, is given by (C3) where γ^w is shown by (C4).

$$w_t^* = p_t + \gamma^w y_t + LN[(W/P)^*] \qquad \text{(C3)}$$

$$\gamma^w = \frac{1}{\eta[1+\theta[1-\alpha(1-\frac{1}{\eta})]]} = \gamma[1+\eta(\frac{1-\alpha}{\alpha})] > \gamma \qquad \text{(C4)}$$

We assume that workers' utility maximisation problem may be approximated by the minimisation of a loss function quadratic in the actual wage relative to the ideal wage given by (C3), the equivalent assumption to that for price setting. Given this the optimisation problem has the same form as (3) except with x^w, the wage set by all workers able to change their wage in a given time period, and w* in place of x and p*. Following this the first order condition (4) follows directly, as do (5)-(8) and the expressions in Appendix B with w and π^w in place of p and π. Substituting from the wage setting version of (B7) and w* from (C3) into the wage setting version of (8) gives x^w for t and t-1 by expressions with the same structure as (9) and (11) except with the change in notation outlined above and the coefficient $\gamma^w+(1-\alpha)/\alpha$ in place of γ. Substitution of these into (12) for π^w gives (13) with the same changes as above. Use of (C2) then gives price inflation in the staggered wages version of the model by (C5) where the first two lines equal wage inflation and the last two lines the difference between price inflation and wage inflation. The coefficients on the output gap and shock terms in (C5) may be expressed more compactly but our focus is on showing that the coefficients on expected inflation in this staggered wages version of the model are the same as the staggered prices version (13).

$$\pi_t = \begin{aligned} & \frac{\beta}{1+\beta q\gamma} E_t[\pi_{t+1}] + k[(\gamma^w + \frac{1-\alpha}{\alpha})y_t + \varepsilon_t + \beta q\gamma E_t[(\gamma^w + \frac{1-\alpha}{\alpha})y_{t+1} + \varepsilon_{t+1}] \\ & + \frac{\beta q\gamma}{1+\beta q\gamma} E_{t-1}[\pi_t] + kq\gamma[[(\gamma^w + \frac{1-\alpha}{\alpha})y_{t-1} + \varepsilon_{t-1} + \beta q\gamma E_{t-1}[(\gamma^w + \frac{1-\alpha}{\alpha})y_t + \varepsilon_t]] \\ & + (\frac{1-\alpha}{\alpha})(y_t - y_{t-1}) + \varepsilon_t - \varepsilon_{t-1} \\ & - \frac{\beta}{1+\beta q\gamma}[E_t[(\frac{1-\alpha}{\alpha})(y_{t+1} - y_t) + \varepsilon_{t+1} - \varepsilon_t] + q\gamma E_{t-1}[(\frac{1-\alpha}{\alpha})(y_t - y_{t-1}) + \varepsilon_t - \varepsilon_{t-1}]] \end{aligned} \quad \text{(C5)}$$

References

Alesina, A., O. Blanchard, J. Gali, F. Giavazzi and H. Uhlig (2001), Defining a Macroeconomic Framework for the Euro Area, Centre for Economic Policy research, London.

Ball, L. and S. G. Ceccheti (1988), Imperfect information and staggered price setting, American Economic Review, 78, 999-1018.

Ball, L. and D. Romer (1989), The equilibrium and optimal timing of price changes, Review of Economic Studies, 56 (April), 179-198.

Barro, R. J. and D. B. Gordon (1983), A positive theory of monetary policy in a natural rate model, Journal of Political Economy, 91/4 pp. 589-610.

Batini, N. and A. G. Haldane (1999), Forward-looking rules for monetary policy, Chapter 4 in J. B. Taylor (ed) "Monetary Policy Rules", NBER and University of Chicago Press.

Batini, N. and A. Yates (2001), Hybrid inflation and price level targeting, Bank of England Working Paper.

Bhaskar, V. (1999), On Endogenously Staggered Prices, mimeo, University of Essex.

Calvo, G. A. (1983), Staggered prices in a utility maximizing framework, Journal of Monetary Economics, 12, 383-398.

Calvo, G. A., Celasun, O. and M. Kumhof (2001), A theory of rational inflationary inertia, mimeo.

Christiano, L. J., M. Eichenbaum and C. Evans (2001), Nominal rigidities and the dynamic effects of a shock to monetary policy, NBER Working Paper No. 8403.

Clarida, R., Gali, J. and M. Gertler (1999), The science of monetary policy: A New Keynesian perspective, Journal of Economic Literature 37, 1661-1707.

Dittmar, R. and W. T. Gavin (2000), What do New Keynesian Phillips curves imply for price level targeting?, Federal Reserve Bank of St Louis Review, March/April.

Dotsey, M., R. G. King and A. L. Wolman (1999), State-dependent pricing and the general equilibrium dynamics of money and output, Quarterly Journal of Economics, 114 (2), 655-690.

Erceg, C. J. and A. T. Levin (2000), Imperfect credibility and inflation persistence, mimeo, Federal Reserve Board.

Estrella, A. and J. C. Fuhrer (1998), Dynamic inconsistencies: Counterfactual implications of a class of rational expectations models, Federal Reserve Bank of New York, October.

Fischer, S. (1977), Long term contracts, rational expectations, and the optimal money supply rule, Journal of Political Economy, 85, No.1, 191-205.

Fuhrer, J. C. and G. Moore (1995), Inflation Persistence, Quarterly Journal of Economics, February pp. 127-159.

Gali, J. and M. Gertler (1999), Inflation dynamics: a structural econometric analysis, Journal of Monetary Economics 44, pp. 195-222.

Gali, J., M. Gertler and J. D. Lopez-Salido (2001), European inflation dynamics, European Economic review, 45/7, 1237-1270.

Goodfriend, M. and R. G. King (2001), The case for price stability, NBER Working Paper No. 8423.

Jensen, H. (1999), Targeting nominal income growth or inflation?, University of Copenhagen working paper.

Kiley, M. T. (1998), Partial adjustment and staggered price setting, Federal Reserve Board.

King, M. (1999), Challenges for Monetary Policy: New and Old, Federal Reserve Bank of Kansas City.

King, R. G. and A. L. Wolman (1996), Inflation targeting in a St Louis model of the 21st century, Federal Reserve Bank of St Louis Review, 78, 83-107.

Mankiw, N. G. (2001), The inexorable and mysterious trade off between inflation and unemployment, Economic Journal, 111/471, C45-C61.

Mankiw, N. G. and R. Reis (2001), Sticky information versus sticky prices: A proposal to replace the New Keynesian Phillips Curve, NBER Working Paper No. 8290.

McCallum, B. T. and E. Nelson (1999), An optimising IS-LM specification for monetary policy and business cycle analysis, Journal of Money, Credit and Banking 31 (August Part 1), 296-316.

McCallum, B. T. and E. Nelson (2000), Timeless perspective vs. discretionary monetary policy in forward-looking models, NBER Working Paper No. 7915.

Nelson, E. (1998), Sluggish inflation and optimising models of the business cycle, Journal of Monetary Economics, 42, 303-322.

Nessen, M. and D. Vestin (2000), Average inflation targeting, Sveriges Riksbank Working Paper Series No. 119.

Roberts, J. M. (1995), New Keynesian Economics and the Phillips curve, Journal of Money, Credit and Banking, 27.

Roberts, J. M. (1997), Is inflation sticky?, Journal of Monetary Economics, 39(2), 173-196.

Rogoff, K. (1985), The optimal degree of commitment to an intermediate monetary target, Quarterly Journal of Economics, 100 (November) pp. 1169-1190.

Rotemberg, J. (1987), The New Keynesian microeconomic foundations, NBER Macroeconomics Annual, 69-114.

Rudd, J. and K. Whelan (2001), A reconsideration of the New Keynesian Phillips Curve, mimeo, federal Reserve Board, February.

Rudebusch, G. D. (2000), Assessing nominal income rules for monetary policy with model and data uncertainty, mimeo (forthcoming, Economic Journal).

Rudebusch, G. D. and L. E. O. Svensson (1999), Policy rules for inflation targeting, in J. B. Taylor (ed) "Monetary Policy Rules", NBER and University of Chicago Press.

Rudebusch, G. D. and L. E. O. Svensson (2000), Eurosystem monetary targeting: lessons from US data, mimeo, Federal Reserve bank of San Francisco.

Sbordone, A. M. (2001), An optimising model of US wage and price dynamics, mimeo.

Soderstrom, U. (2001), Targeting inflation with a prominent role for money, Sveriges Riksbank Working Paper No. 123.

Steinsson, J. (2000), Optimal monetary policy in an economy with inflation persistence, Central Bank of Iceland Working Papers, No. 11, December.

Taylor, J. B. (1979), Staggered wage setting in a macro model, American Economic Review, 69 (May), 108-113.

Taylor, J. B. (1980), Aggregate dynamics and staggered contracts, Journal of Political Economy, 88, 1-23.

Taylor, J. B., ed., (1999a) Monetary Policy Rules, NBER and University of Chicago Press.

Taylor, J. B. (1999b), Staggered price and wage setting in macroeconomics, Chapter 15 in J. B. Taylor and M. Woodford (eds) Handbook of Macroeconomics, Volume 1B, North-Holland.

Walsh, C. E. (1995), Optimal contracts for central bankers, American Economic Review, 85/1 pp. 150-167.

Walsh, C. E. (1998), Monetary Theory and Policy, MIT Press.

Walsh, C. E. (2001), The output gap and optimal monetary policy, mimeo.

Wolman, A. L. (1999), Sticky prices, marginal cost, and the behaviour of inflation, Federal Reserve Bank of Richmond Economic Quarterly, 85/4, Fall.

Wolman, A. L. (2000), The frequency and costs of individual price adjustment, Federal Reserve Bank of Richmond Economic Quarterly, 86/4, Fall.

Woodford, M. (1999), Optimal monetary policy inertia, NBER Working Paper No. 7261.

Woodford, M. (2001), Optimising Models with Nominal Rigidities, Draft Chapter 3 of "Interest and Prices", December.

Woodford, M. (2000), A Neo-Wicksellian Framework, draft Chapter 4 of "Interest and Prices", September.