ISSN 1471-0498

DEPARTMENT OF ECONOMICS

DISCUSSION PAPER SERIES

OPTIMISING MICROFOUNDATIONS FOR INFLATION PERSISTENCE

Richard Mash

Number 183

January 2004

Manor Road Building, Oxford OX1 3UQ

Optimising Microfoundations for Inflation Persistence

Richard Mash[1]

Department of Economics and New College
University of Oxford

January 2004

Abstract

Much recent monetary policy literature has searched for models suitable for policy analysis that are based on optimising microfoundations and consistent with the data, especially observed persistence of inflation and the output gap. Few models do well on both criteria. We derive an optimising Phillips curve based on a much more general time dependent pricing rule than that underpinning current models and calibrate it using microeconomic evidence on price changing behaviour. The more general, calibrated pricing rule predicts inflation and output persistence comparable to that in the data without reliance on rule of thumb behaviour, indexing or serially correlated shocks.

JEL E52, E58, E22

Key Words: Monetary policy, Phillips curve, Inflation persistence, Microfoundations

I am very grateful for comments and suggestions from Chris Bowdler, Jagjit Chadha, John Driffill, Petra Geraats, Roland Meeks, John Muellbauer, Neil Rankin, Mathan Satchi, Dennis Snower, David Vines and Stephen Wright, and participants at seminars at Birkbeck, Cambridge, Cardiff, Oxford and the University of East Anglia, and the conferences, "Financial Markets, Business Cycles and Growth", Birkbeck College, 14-15 March 2003; the Econometric Society North American Summer Meeting, NorthWestern University, 26-29 June 2003; the Money, Macro and Finance Study Group Annual Conference, Cambridge, 10-12 September 2003 and "Recent Developments in New Keynesian Macroeconomics", Birmingham, 31 October, 2003. I am also very grateful to Richard Friberg for detailed data from Apel et. al. (2001). All errors and interpretations are my own.

---

[1]Correspondence: New College, Oxford, OX1 3BN, UK; Tel. +44-1865-289195; Fax +44-1865-279590; email: richard.mash@economics.ox.ac.uk.

Introduction

A central objective of the monetary policy literature has been the search for structural models of the macroeconomy suitable for use in policy analysis. Key criteria for such a model are that it should be based on optimising microfoundations, both for conceptual coherence and to avoid Lucas critique problems in policy analysis, and that it should be able to account for key features of the data, including inflation and output gap persistence. Most models currently in use satisfy one or other of these criteria but not both, with much of the debate concentrating on the appropriate specification for the aggregate supply or Phillips curve relationship.[2] The key contribution of this paper is to derive a well microfounded Phillips curve that can account for at least a large fraction of the persistence that we see in the data. This result follows from the derivation of the Phillips curve for a much richer time dependent pricing rule than the Calvo (1983) form used in most current models and its calibration using microeconomic evidence on price changes. The optimising microfoundations of the new model are identical to those of the standard Calvo model in the sense that all behaviour is optimising given the pricing rule.

In relation to the literature, the failure of the standard Calvo model to match empirical persistence (without serially correlated shocks) is well known[3] and has led many analysts to use the Phillips

[2]Woodford (2003) and Rudebusch (2002) give excellent summaries of this controversy.

[3]See the discussion in Clarida, Gali and Gertler (1999) together with a large number of other contributions including Calvo, Celasun and Kumhof (2001), Christiano, Eichenbaum and Evans (2003), Dotsey (2002), Eichenbaum and Fisher (2003), Fuhrer and Moore (1995), Gali and Gertler (1999), Gali, Gertler and Lopez-Salido (2001), Jensen (2002), Mankiw (2001), Mankiw and Reis (2002), McCallum (1999), Nelson (1998), Nessen and Vestin (2000), Roberts (1997, 2001), Rudd

curve (1) which adds lagged inflation to the Calvo form (where μ=1).[4]

$$\pi_t = \mu\beta E_t[\pi_{t+1}] + (1-\mu)\pi_{t-1} + \gamma y_t + \varepsilon_t \qquad (1)$$

While (1) successfully predicts persistence, a considerable debate has arisen over the interpretation of the lagged inflation term in relation to optimising behaviour. Most simply this term could be an ad hoc addition for empirical fit or reflects adaptive expectations of inflation, neither of which are satisfactory. More recently some authors have shown that this term is present if wage or price setters use rules of thumb or index their prices using lagged inflation.[5] The extent to which these are optimising microfoundations is open to debate and arguably not sufficiently well established to preclude the search for other models that are also broadly data consistent but more clearly based on optimising behaviour. The Calvo pricing rule underlying (1) is also not well supported by the microeconomic evidence on pricing behaviour.

We also briefly note four further potential explanations for inflation persistence, arguing that these

---

and Whelan (2001), Rudebusch (2002), Sbordone (2001), Soderstrom, Soderlind and Vredin (2002), Steinsson (2003), Taylor (1999), Walsh (2003a,b), Wolman (1999) and Woodford (2003). Some authors (including Gali and Gertler, 1999; Sbordone, 2002; and Gali, Gertler and Lopez-Salido, 2001) suggest that the empirical failure of the Calvo model can be overcome by using marginal cost rather than the output gap as the driving variable for inflation. However, Eichenbaum and Fisher (2003) use marginal cost and find that indexation using lagged inflation is required to match the data. Adam and Padula (2003) present similar results.

[4]The notation is standard; π, β, y, ε are inflation, the private sector discount factor, the output gap and the cost push or inflation shock respectively. Some formulations replace the output gap with marginal cost.

[5]See Gali and Gertler (1999), Christiano, Eichenbaum and Evans (2003), Eichenbaum and Fisher (2003), Steinsson (2003), Sbordone (2001) and Woodford (2003).

also do not fully resolve the tension between optimising microfoundations and empirical performance. The first is the relative real wage structure of Fuhrer and Moore (1995) which is generally regarded as not reflecting optimising behaviour (see Taylor, 1999). The second, Erceg and Levin (2000), explains persistence with adaptive learning by agents in response to a change of policy regime. This model has very explicit microfoundations and is likely to partly explain persistence but it has difficulty in accounting for continued persistence during periods when the policy regime has been fairly stable, the evidence for which we discuss later. Thirdly, Mankiw and Reis (2002) present a Phillips curve with a substantial amount of price setting based on lagged information and analyse its predictions for inflation persistence. This structure gives rise to a delayed and sluggish response of prices and inflation to persistent monetary policy shocks but there is no demonstration of persistence in the sense of positive serial correlation in response to transient shocks in the absence of serial correlation in the driving process. Fourthly, Reis (2003) shows that deviations of inflation from target may be persistent if policy makers do not know the natural rate with certainty since they will make persistent policy errors during their learning process. This is clearly plausible but it is not fully established that this will explain the major part of the persistence that we observe. Reis assumes quite a high degree of serial correlation in the supply shock to match the data.

While the literature has focussed on macroeconomic data consistency, a further empirical dimension concerns the microeconomic evidence on pricing behaviour, especially the age structure of prices in the aggregate price level rather than simply average price duration. With the exception of Wolman (1999) and Kiley (2002) this has received rather little attention but it is surely desirable for nominal rigidities to be introduced in a way that is consistent with the microeconomic evidence. In this regard (1) is open to criticism since it is based on Calvo pricing which is not supported by the micro evidence on price durations, even though it can be calibrated to reflect average duration.

In this paper we retain the time dependent pricing approach but allow for a much more general pricing rule than the Calvo assumption that the probability of price change is constant and thus invariant to the time since the last price change. This is motivated by a review of the microeconomic evidence on price changing behaviour which suggests that we should move away from a constant to an increasing probability of price change. This requires a much more general model of the Phillips curve in relation to the underlying pricing rule than currently exists. The derivation of that model may be regarded as an independent contribution to the theory of the Phillips curve but we also calibrate it using the micro evidence to assess macroeconomic data consistency. This is done by assuming a standard discretionary policy maker and focussing on the predicted degree of persistence in inflation and output relative to that observed in actual data. Our headline result is that the microfounded generalised Phillips curve predicts outcomes close to the macro data when calibrated using the micro data. This occurs without rule of thumb behaviour, indexing or serial correlation in the shock process and hence, subject to the interpretation of the data, the model combines the desired features of optimising microfoundations and consistency with both macro and micro data.

While this result is new, the paper is by no means the first to question the widespread use of Calvo pricing. Key contributions include Khan, King and Wolman (2002), Kiley (2002), Dotsey and King (2001), Wolman (1999) and Dotsey (2002). These papers also suggest potential sensitivity of monetary policy results to changes in the underlying pricing rule, a further motivation for the analysis. Mash (2003a) finds significant changes to optimal monetary policy delegation even with a much more limited variation away from Calvo pricing than that considered here.

The paper's scope is restricted to time dependent pricing rules whereas in principle it would be preferable to have state dependent pricing models. Unfortunately the latter are much more difficult to work with and rarely give tractable results so virtually all monetary policy models with nominal rigidities are based on time dependent pricing (and almost always of the Calvo form). Given the dominance of the time dependent approach and its use in generating policy recommendations it is clearly useful to know which pricing rules give us models close to the data, the task of this paper, as well as their policy implications which we do not consider. This program could be seen as a stepping stone between the current workhorse models based on a rather simple time dependent rule (Calvo pricing) and future models based on full state dependence. At the same time it is possible that results would not change greatly with state dependent pricing. Woodford (2003) argues that in reasonably stable macroeconomic environments time dependent and state dependent results will be similar, a view supported by Burstein's (2003) analysis. Wolman (1999) argues that the type of time dependent pricing rule supported by the micro data is consistent with the predictions of Dotsey, King and Wolman (1999) which is arguably the most fully developed state dependent model available.

The remainder of the paper is structured as follows. Section 1 reviews microeconomic evidence on price setting to establish the form of time dependent pricing supported by the micro data. Section 2 derives the generalised Phillips curve that may be calibrated using the micro evidence and Section 3 simulates the calibrated model to assess its macro data consistency. Section 4 concludes.

1. Microeconomic evidence on firms' pricing behaviour.

We consider the microeconomic evidence on firms' price setting behaviour to determine which forms of time dependent pricing rules are micro data consistent. Interpretation of the evidence requires a degree of judgement but nevertheless it suggests a reasonably narrow range of possibilities. Our core sources are the survey results of Blinder et. al. (1998) for the US together with Hall, Walsh and Yates (2000) for the UK and Apel, Friberg and Hallsten (2001) for Sweden. Wolman (2000) provides a very useful review of this literature. Each survey asks how many times the respondent firm's price (or the price of their main product) changes in either a typical year or the last year. The responses are reported in the first four columns of the upper part of Table 1. To derive the pricing rules which are consistent with this evidence we first translate the frequency of price changes into price duration. This requires some assumptions about the correspondence between them since, for example, if a firm has changed its price once in the last year, it may have a typical price duration of exactly four quarters but equally it may have duration of three or five or more quarters. The assumptions made are embodied in the weighting factors in the upper right part of Table 1 where D1, D2 etc. refer to durations of one, two etc. quarters and the figures in each row allocate the price change frequency information from the surveys to each duration. The results of this are shown in the lower left of Table 1. These weighting factors are chosen for plausibility rather than from direct empirical evidence. Clearly different judgements could be made but some assumptions are unavoidable and we address the sensitivity of the results to these below.

Table 1. Microeconomic survey data on price changing and duration/probability of price change derivations.

Number of price changes:	US	UK	Sweden	Flex	D1	D2	D3	D4	D5	D6	D7
				Assumed duration weighting factors:							
<1	0.1	0.06	0.29						0.50	0.35	0.15
1	0.39	0.37	0.43				0.20	0.45	0.20	0.10	0.05
1.01-2	0.16					0.40	0.60				
2		0.26	0.06			0.60	0.40				
2.01-4	0.13			0.10	0.55	0.35					
3			0.02		0.60	0.40					
3-4		0.18		0.20	0.70	0.10					
4			0.04	0.30	0.70						
>4	0.22	0.14	0.16	1							

Implied duration:

	US	UK	Sweden	Wol.	Calvo
Flex	0.23	0.17	0.18		
1 period	0.07	0.12	0.05	0.02	0.25
2 periods	0.11	0.17	0.04	0.05	0.19
3 periods	0.17	0.18	0.11	0.12	0.14
4 periods	0.18	0.17	0.19	0.18	0.11
5 periods	0.13	0.10	0.23	0.22	0.08
6 periods	0.07	0.06	0.14	0.21	0.06
7 periods	0.03	0.03	0.06	0.21	0.04

Implied probability of price change:

	US	UK	Sweden	Wol.	Calvo
q0	0	0	0	0	0
q1	0.09	0.15	0.05	0.02	0.25
q2	0.15	0.25	0.06	0.05	0.25
q3	0.29	0.33	0.15	0.13	0.25
q4	0.42	0.47	0.31	0.22	0.25
q5	0.54	0.55	0.52	0.35	0.25
q6	0.68	0.68	0.69	0.5	0.25
q7	1	1	1	1	0.25

Sources:

US data is from Blinder et. al. (1998), Table 4.1 on page 84.

UK data is from Hall et. al. (2000), Figure 7. These numbers are taken from the Figure since they are not reported numerically in the paper. Hence they may be approximate rather than exact.

Swedish data is from the survey reported by Apel et. al. (2001), Question 10 and is turnover weighted. I am very grateful to Richard Friberg for providing these figures which give greater detail than in the text of the paper. The original turnover weighted data has been adjusted slightly to exclude a small number of firms which responded "other" to this question such that the proportions in the column for Sweden above sum to unity.

"Wol." above refers to Wolman (1999). The probabilities under "Wol." in the lower right hand part of the table are taken (with possible slight measurement error) from Wolman (1999) Figure 1a "Preferred" series. In this series there are also probabilities of price change less than one for periods 7 and 8 but we truncate the series such that the probability of price change goes to unity eight periods after a price change. This is done for comparability with the other series and consistency with our solution procedure.

A further issue is how to deal with prices that change four or more times a year. It seems likely that at least some of these prices are essentially flexible rather than being set potentially for many periods but then changed almost immediately. Hence we assume a separate flexible price category ("Flex") and attribute to it all prices that are changed more than four times a year and a small proportion of those changed four (or 3-4 or 2.01-4) times a year. As a sensitivity check we later show results with these prices assumed part of the time dependent pricing rule.

Given the price duration information in the lower left of Table 1 there is a choice to be made about the nature of the underlying pricing rule (for those prices not taken as flexible). One possibility would be to assume deterministic, Taylor (1979, 1980) pricing, and construct a Phillips curve from aggregating 2-7 period Taylor models using the duration figures in Table 1 as weights (and with the prices which last for one period assumed flexible). Under this interpretation, firms are assumed to know the exact duration of their prices when those prices are reset. A second possibility follows from the Calvo approach under which firms do not know the exact duration of new prices when they are reset but do know the probability of the new price being reset again in subsequent periods. In the Calvo model those probabilities are assumed equal but a more desirable approach is to derive the probabilities which would give rise to the empirical durations shown in Table 1.

The generalised Phillips curve of the next section encompasses both the deterministic and stochastic approaches but our later simulations focus on the latter, partly to remain closer to the Calvo approach dominant in the literature. To implement that, we derive the probabilities of price change, shown in the lower right of Table 1, which would generate the duration data shown in the lower left part.

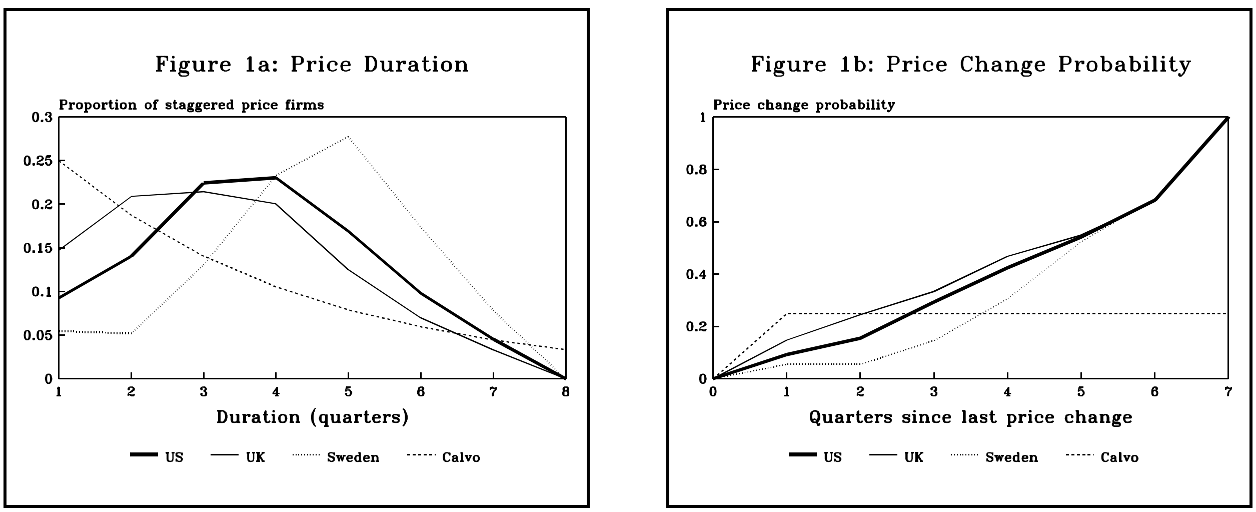
This is straightforward and does not require any assumptions. The notation for the price change probabilities is q_1, q_2, ... , q_i for the probability of a price change 1, 2, ... , i periods after the price has been reset. It is also convenient to define q_0 (=0) as the probability of a further price change in a period after a new price has already been set at the start of that period. The weighting factors allow for prices to last for up to seven quarters so q_7=1 by assumption.

The lower part of Table 1 includes two further series for comparison. The first "Calvo" assumes a constant probability (of 0.25, a typical calibration implying average duration of four quarters). The second, "Wol." comes from Wolman (1999) and is based on his preferred calibration of price change probabilities. These are informed by his literature review but it is not clear whether they are derived explicitly as above or chosen directly.

Figure 1a shows price duration for the three countries plus that implied by the Calvo model. The duration distributions for each country are hump shaped but average duration is shorter for the UK than Sweden with the US between them. In Figure 1b this corresponds to higher (lower) probabilities of price change in the first four quarters for the UK (Sweden) than the US. The probabilities of price change are common thereafter due to the common weighting of prices changed once or less than once a year in Table 1.

Figure 1b shows that the Calvo constant probability assumption does not appear to be consistent with the data which instead suggests an increasing probability of price change as in Wolman (1999). For duration, Figure 1a shows that the Calvo model predicts that a single period would be the most common duration with frequency declining thereafter. This contrasts with the hump-shaped profile derived from the surveys. This conclusion could also be reached directly from the raw data in Table 1. For each country the most common price change frequency is once per year which is inconsistent with the Calvo prediction, for the quarterly models standard in the literature, that modal duration would be one quarter. This both questions the microeconomic data consistency of the Calvo pricing rule of thumb/indexing model (1) and motivates the derivation of a more general Phillips curve.

Figure 1: Results from micro data (excluding flexible prices)

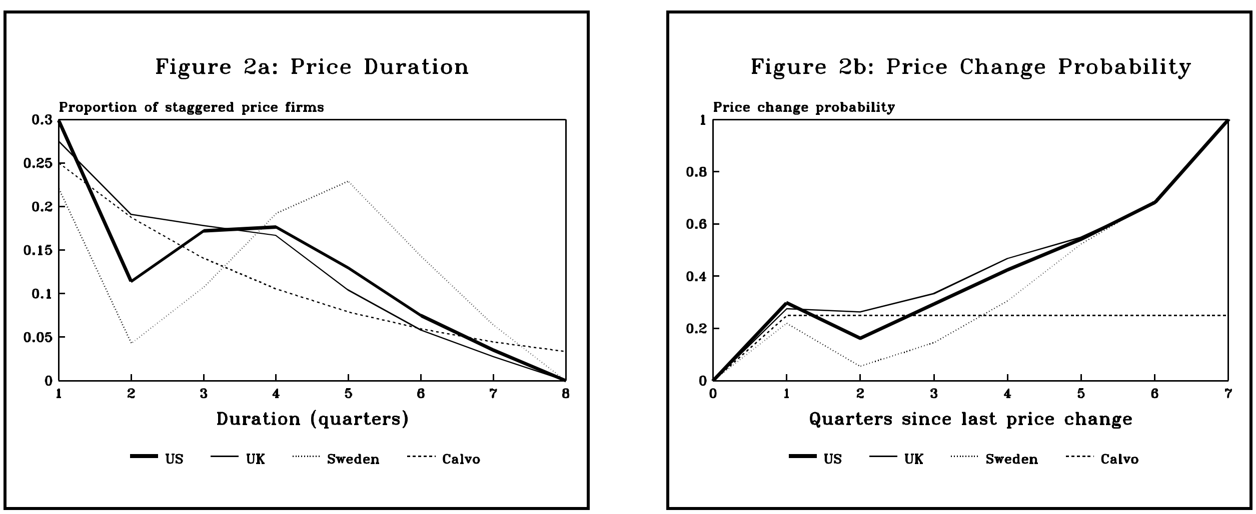


We briefly comment on the possible robustness of the evidence shown in Figures 1a and 1b. Firstly these reflect the duration weights in Table 1 which were chosen for plausibility but without explicit empirical justification. Hence this exercise could be interpreted as a first cut at the likely distribution of price duration pending more detailed empirical evidence. However, given that the duration distributions for the UK and Sweden in Figure 1a fall to either side of the US by some margin their simulations will act as a sensitivity check on the US results. We find that the results differ between the three countries but not unduly so and hence our conclusions should be reasonably robust to the weighting assumptions. Secondly, from Table 1 the Wolman (1999) probabilities lie below those derived for the three countries so it is possible that the weighting factors have unduly shortened the duration distribution. At the same time the duration frequencies corresponding to the Wolman probabilities are high at quarters 5-7 relative to the survey responses unless many of the firms reporting one price change in a year have durations rather longer than a year. Thirdly, Apel et. al. (2001) comment that the UK survey has a possible over representation of manufacturing firms who tend to have shorter price duration. This would imply that the UK duration profile in Figure 1a is too short and hence the UK probability sequence in Figure 1b too high for the first few quarters.

The latter two points suggest that more weight should be given to the US and Swedish calibrations, but a counter-argument may be the US evidence presented in Bils and Klenow (2002) who argue that their results imply much more frequent price changes than other sources. We do not report their evidence in detail since it is primarily presented in terms of frequency of price changes, corresponding to the average probability of price change, which is less helpful than the surveys above for deriving duration and hence probability sequences. They do, however, report an average price duration in their sample of seven months (page 15) and also show that their sample contains many prices which are temporarily discounted before returning to their original values. If these are excluded (see Gali, 2003) it is possible that average duration would rise to approximately three quarters which is close to the mean of the UK distribution in Figure 1a and a little below the mean for the US from the Blinder et. al. (1998) data. Hence the latter may overstate price duration for the US, but it is not clear by how much.

A further sensitivity issue is our assumption that the frequently changed prices are flexible rather than being set according to a time dependent pricing rule with a high probability of price change in the quarter following a price change. Figure 2 corresponds to Figure 1 but with the assumption that all prices previously considered flexible are attributed to short duration parts of the pricing rule. For this the weights under "Flex" in the upper right of Table 1 are replaced by zeros and transferred to D1 for responses 4 and >4, and D1 and D2 in proportion to the weights shown for responses 2.01-4 and 3-4. This raises the early part of the probability sequences in Figure 2b. In turn it moves the interpretation of the empirical evidence a little closer to the Calvo model but it is not clear how much weight should be given to this case since it seems highly plausible that a proportion of prices will be flexible rather than sticky. For completeness we report results later using the probabilities in Figure 2b as well as those in Figure 1b. Predicted persistence falls but remains positive and greater than that for the Calvo model.

Figure 2: Results from micro data ("flexible" prices part of staggered prices)



2. The Generalised Phillips Curve

We derive a generalised model of the Phillips curve under time dependent pricing, the key innovation being to allow the probability of price change to vary with the time since the last price change. This considerably generalises existing models of the Phillips curve while also facilitating calibration with the micro data. The model extends that of Dotsey (2002) which in turn relates to Wolman (1999) and Kiley (2002). The Dotsey model allows the probability of price change to rise for two periods before going to unity and we generalise this so the probability may vary for any number of periods before going to unity. In addition we allow for cost push shocks which are important for the simulation results as well as being highly relevant for policy analysis. We first present the derivation for a stochastic pricing rule shared by all firms prior to allowing for some flexible price firms and aggregation across groups of firms with different pricing rules, including the multiple Taylor interpretation of the duration data.

The notation for the per period probability of price change i periods after the last price change is q_i as above with the last period in which the price may remain fixed denoted T such that prices may remain fixed for up to T+1 periods (allowing for period 0). We emphasise that these probabilities may take any values (between zero and unity) and follow any time profile (rising, falling or constant, though the first of these fits the micro data), and that T can tend to infinity. Together these allow for a Calvo type infinite horizon as well as truncation of the possible duration of fixed prices. It is convenient to define the cumulative probability of a price remaining fixed j periods after a price change by Q_j which is given by (2) together with two summary parameters, Q and Q'.

$$Q_j = \Pi_{i=0}^{j}(1-q_i) \qquad Q = \Sigma_{j=0}^{T}\beta^j Q_j \qquad Q' = \Sigma_{j=0}^{T}Q_j \tag{2}$$

We turn to the optimisation decision of a firm that is able to change its price, following the standard derivation of the Calvo model (see Walsh, 2003a) except with the more general pricing rule. Hence we adopt the relatively simple log linear structure (around a zero inflation steady state) that has become standard (see Dotsey, 2002) in that the ideal (log) price that would be set with complete price flexibility (so other time periods have no bearing on the current price decision) denoted x* is given by (3) where p is the log price level. We assume flexible wages so the output gap is proportional to marginal cost so either of them may be used in (3) with appropriate scaling for γ.

$$x_t^* = p_t + \gamma y_t + \varepsilon_t \tag{3}$$

Given x* the firm's optimisation problem is approximated by the minimisation of V_t in (4) by the choice of its price, x_t, that will remain in place for some number of periods according to the price change probabilities. We assume that all firms which set new prices at t have full information up to and including that period.

$$V_t = E_t\Sigma_{i=0}^{T}\ \beta^i Q_i(x_t - x_{t+i}^*)^2 \tag{4}$$

Minimisation of (4) gives the first order condition (5) where the optimal price is a discounted and survival probability weighted average of expected ideal flexible prices.

$$x_t = E_t\Sigma_{i=0}^{T}\ \frac{\beta^i Q_i}{Q} x_{t+i}^* \tag{5}$$

Substituting from (3) with ε assumed iid into (5) gives (6), where the last term relates to price levels, and (7) where this is expressed in terms of inflation rates and p_t.

$$x_t = \frac{1}{Q}[\varepsilon_t + \gamma E_t \Sigma_{i=0}^{T} \beta^i Q_i y_{t+i} + E_t \Sigma_{i=0}^{T} \beta^i Q_i p_{t+i}] \tag{6}$$

$$x_t = \frac{1}{Q}[\varepsilon_t + \gamma E_t \Sigma_{i=0}^{T} \beta^i Q_i y_{t+i} + Q p_t + E_t \Sigma_{i=1}^{T} \Sigma_{j=i}^{T} \beta^j Q_j \pi_{t+i}] \tag{7}$$

The Phillips curve is derived from (7) and the aggregate price level shown by (8) which includes current and earlier set prices with weights given by their relative survival probabilities. The price level in the time dependent or staggered price sector is p^s. In the core version of the model this is also the aggregate price level but it is helpful to express it in this way for aggregation below.

$$p_t^s = \Sigma_{k=0}^{T} \frac{Q_k}{Q'} x_{t-k} \tag{8}$$

Lagging (7) and substituting for each x_{t-k} into (8) gives (9) where the summary term, z_{t-k}, is given by (10) and groups together all expectations formed at t-k.

$$p_t^s = \Sigma_{k=0}^{T} \frac{Q_k}{Q'}[p_{t-k} + \frac{1}{Q}(\varepsilon_{t-k} + \gamma y_{t-k} + z_{t-k})] \tag{9}$$

$$z_{t-k} = E_{t-k}[\gamma \Sigma_{i=1}^{T} \beta^i Q_i y_{t-k+i} + \Sigma_{i=1}^{T} \Sigma_{j=i}^{T} \beta^j Q_j \pi_{t-k+i}] \tag{10}$$

Next we re-express the price terms on the right hand side of (9) in terms of inflation rates and the time t aggregate price level to give (11) where the third term is present if T exceeds unity.

$$p_t^s = p_t - \frac{(Q'-1)}{Q'} \pi_t - \Sigma_{k=1}^{T-1} \Sigma_{j=k+1}^{T} \frac{Q_j}{Q'} \pi_{t-k} + \Sigma_{k=0}^{T} \frac{Q_k}{Q'Q}(\varepsilon_{t-k} + \gamma y_{t-k} + z_{t-k}) \tag{11}$$

In the simple case of a single pricing rule shared by all firms, $p^s = p$ so these terms cancel from (11) in which case moving π_t to the left hand side gives the Phillips curve (12).

$$\pi_t = \Sigma_{k=0}^{T} \frac{Q_k}{(Q'-1)Q}[\varepsilon_{t-k} + \gamma y_{t-k} + z_{t-k}] - \Sigma_{k=1}^{T-1}\Sigma_{j=k+1}^{T}(\frac{Q_j}{Q'-1})\pi_{t-k} \qquad (12)$$

From (12) inflation depends on the current and past values of the output gap, shock variable, lagged inflation (with negative coefficients) and, in the z terms, current and past forward looking expectations of future (from the point of view of the expectations date) output gaps and inflation. Each value of the summation parameter, k, in (12) corresponds to different dated prices in (8) and thus the influence on current inflation of the cohort of prices set k periods ago.

To anticipate our later results, (12) shows that serial correlation in inflation may arise from the presence of both current and lagged shock terms since an inflation increasing shock will first appear as ε_t but will impact positively on inflation for T+1 periods since it will also appear successively as ε_{t-1}, ε_{t-2} etc. It turns out that this effect is not fully offset by the negative lagged inflation terms.

We briefly discuss two extensions. The first is to allow for the flexible price sector suggested by the micro data. The setting of these prices, denoted p^f, follows from (3) except that for simplicity we assume that these prices are not subject to shocks and hence p^f=p+γy in each time period. These may readily be aggregated with the staggered price sector using (11). If we define the shares in the aggregate price level by F for flexprice firms and S (=1-F) for staggered prices the log aggregate price level is Fp^f+Sp^s which may be expanded to give (13).

$$p_t = F[p_t^f + \gamma y_t] + S[p_t^s - \frac{(Q'-1)}{Q'}\pi_t - \Sigma_{k=1}^{T-1}\Sigma_{j=k+1}^{T}\frac{Q_j}{Q'}\pi_{t-k} + \Sigma_{k=0}^{T}\frac{Q_k}{Q'Q}(\varepsilon_{t-k} + \gamma y_{t-k} + z_{t-k})] \qquad (13)$$

The aggregate price level cancels from the left and right hand sides of (13) so π_t may be moved to the left hand side to give this Phillips curve by (14) where the presence of flexprice firms increases the sensitivity of inflation to the current output gap compared with (12).

$$\pi_t = \frac{FQ'}{S(Q'-1)}\gamma y_t + \Sigma_{k=0}^{T} \frac{Q_k}{(Q'-1)Q}[\varepsilon_{t-k} + \gamma y_{t-k} + z_{t-k}] - \Sigma_{k=1}^{T-1}\Sigma_{j=k+1}^{T}(\frac{Q_j}{Q'-1})\pi_{t-k} \qquad (14)$$

The second extension is the possibility of aggregating two or more staggered price sectors with different pricing rules. This is attractive for generality since it allows for the possibility of different pricing rules in different parts of the economy, though we do not pursue this case below. Aggregation follows from the aggregate price level for this case being the weighted average of the price level in each staggered price sector with the weights being their share in all prices and summing to unity (or 1-F if there are also flexible prices). Hence the aggregate price level may be expressed by the sum of each sectoral weight multiplied by the right hand side of (11) evaluated for each sector (with different values of the Q and T parameters) plus possible flexible prices. Since the combined weights sum to unity, the aggregate price level will cancel from each side of the resulting expression, as with (13)-(14), to give an aggregate Phillips curve of the form (12) or (14) but with the coefficients reflecting weighted averages of the coefficients for each sector. This may be done for any number of sectors. A special case is a multiple Taylor model where the parameters in (2) for each Taylor sector (defined by the duration of its prices) simplify by the probabilities being zero for the relevant number of periods followed by unity.

3. Simulation Results: Inflation and Output Persistence

This section simulates the new Phillips curve, calibrated to the micro data, and compares its predictions with evidence from macro data. We discuss in turn the approach taken to comparing model predictions with data, the way in which the model is simulated, the macro evidence with which we make comparisons and the results of the simulations.

The process of taking macroeconomic models to the data is both complex and controversial. We adopt a very simple approach focused on the persistence issue while acknowledging that much more sophisticated work could be done. In particular we compare the persistence properties of inflation and the output gap, summarised by their autocorrelation functions, with predictions from the model once we allow for optimising policy responses to the cost push shocks. This corresponds to the approach of Soderstrom, Soderlind and Vredin (2002) and has the virtue of focusing directly on persistence which has been the centre of empirical debate about the Phillips curve. It also captures the idea of the model being subject to control rather than subject to exogenous shocks with no feedback from policy responses. We do not attempt econometric estimation of the model, which is likely to be problematic given the presence of many different dated expectations in the Phillips curve, nor do we make comparisons with VAR evidence. The latter is a common approach but we do not pursue it since the presence of lagged shock terms in the Phillips curve means that the model has a VARMA rather than VAR reduced form.[6]

---

[6]A related point is that if the model of this paper is the true model there will be an element of misspecification in VAR based exercises, especially those with restricted lag lengths. The quantitative significance of this is unclear but the recent work of Klaeffing (2003) questions a

We assume that there is a simple optimising policy maker who minimises a standard loss function with the Phillips curve the constraint on that optimisation. We focus on optimal responses to cost push shocks, traditionally a central concern of the monetary policy literature, leaving aside demand and other possible shocks.[7] We also assume that the policy maker acts under discretion which seems appropriate for comparing model predictions with actual outcomes. A further choice is the specification of the policy loss function. If our aim was to derive fully optimal policy it would be appropriate to derive the true social loss function for the model but since our purpose is positive rather than normative we assume simple quadratic forms typical in the literature. In particular we report results for the loss functions (15), the standard quadratic, and (16) which replaces quarterly inflation with annual inflation (since the sum of the inflation terms shown is p_{t-s}-p_{t-s-4}). The inflation target is set to zero in each case for simplicity. While (15) is often used, Soderstrom, Soderlind and Vredin (2002) argue that the mandates of central banks typically specify annual rather than quarterly inflation in which case (16) is more appropriate. This argument applies directly to the UK and Swedish central banks which have annual inflation targets. The Federal Reserve does not have an explicit inflation target and hence the choice is less clear but it seems plausible that (16) is at least as likely as (15) to reflect US policy preferences.

---

number of generally accepted results from VAR analyses once the possibility of a VARMA structure is introduced. In particular he finds that the peak responses of inflation and output to shocks may occur much more quickly than VAR estimates would suggest.

[7]If there is no interest rate smoothing objective, demand shocks would be fully offset under full information and thus not affect outcomes for inflation and the output gap. In addition we may model the policy maker as choosing inflation and the output gap directly without reference to the transmission mechanism (McCallum and Nelson, 2000). Given that control errors are likely it would be of interest to include them but we leave this to future research. A conjecture is that the similarity in the lag structure of (12) for the output gap (and thus control errors) and cost push shocks may make their effects comparable.

$$L_s = E_s \Sigma_{t=s}^{\infty} \beta^{t-s} (\pi_{t-s}^2 + \lambda y_{t-s}^2) \tag{15}$$

$$L_s = E_s \Sigma_{t=s}^{\infty} \beta^{t-s} [(\frac{\pi_{t-s} + \pi_{t-s-1} + \pi_{t-s-2} + \pi_{t-s-3}}{4})^2 + \lambda y_{t-s}^2) \tag{16}$$

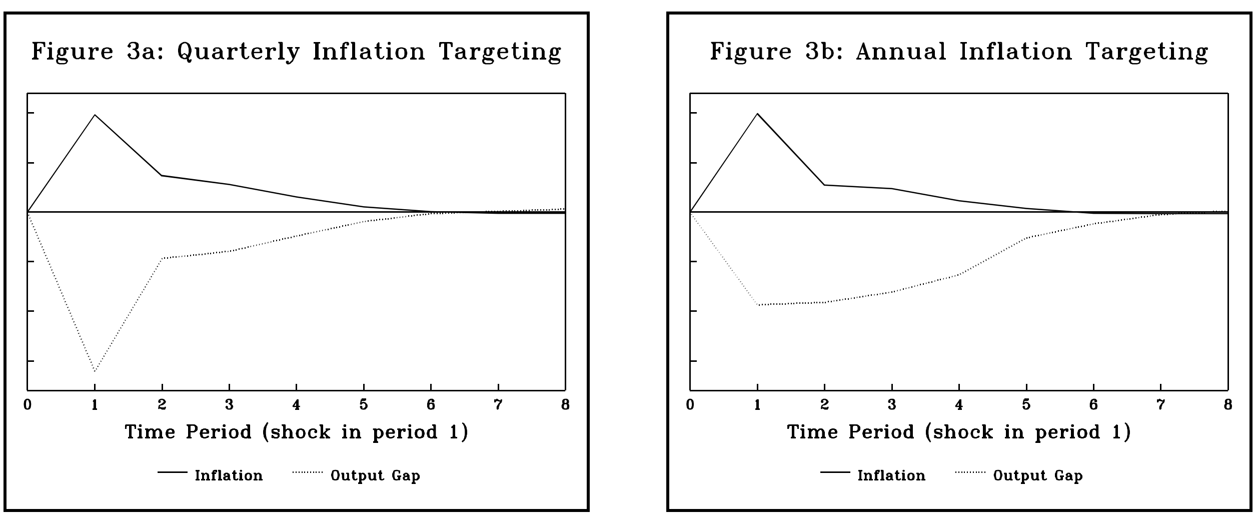
Remaining choices concern the parameters β and λ in the loss functions and γ in the Phillips curves (12) and (14). All other coefficients arise from the time dependent pricing rule which we calibrate using the micro data. We follow standard practice in setting β=0.99 for a quarterly model. For λ we could choose a plausible value and keep it fixed across all the simulations, or we could allow it to vary as part of the data matching exercise. The former is the simplest approach but it gives rise to a very wide range of values for the relative variability of inflation and output across the simulations. Since we have data on this which can be matched the first approach seems unsatisfactory and we adopt the second. In particular we solve the model for given values of β and γ plus the pricing rule underlying the Q coefficients in the Phillips curve, but vary λ in the loss function so the ratio of the variances of inflation and the output gap is 0.4, a figure calculated from the evidence presented in Soderstrom, Soderlind and Vredin (2002, Table 1). The results are not particularly sensitive to this figure but would change if we allowed the relative variances to move far from the data. Hence this aspect of data consistency is ensured as well as consistency with the micro data by calibration.[8] The remaining parameter, γ, the sensitivity of the ideal single period flexible price to the current output gap, is set at 0.15 which is plausible given its microfoundations (see Mash, 2003a, Appendix A).

[8]In common with Soderstrom, Soderlind and Vredin (2002) we find that the required values of λ are quite small, typically in the range 0.01-0.1.

Experimentation showed only modest sensitivity of the results to this parameter. For conciseness we do not present the solution to the policy optimisation which is derived in Mash (2003b) as an extension to that in McCallum and Nelson (2000).

As a preliminary step, Figure 3 shows the impulse responses for a baseline case of the US probabilities of Figure 1b and the US share of flexible prices in Table 1 and hence using Phillips curve (14). Figure 3a uses (15) which we term quarterly inflation targeting while Figure 3b uses (16) for annual inflation targeting, our preferred specification. Given a single iid cost push shock the dynamics of the model gives rise to persistence in both inflation and the output gap. Figure 3a contrasts markedly with the Calvo model's impulse responses which have a single spike at the time of the shock under quarterly inflation targeting. Annual targeting Calvo results are shown below. A consistent pattern in the later results visible in Figure 3 is the similar persistence of inflation and the output gap under quarterly targeting but a more persistent output gap with annual targeting.

Figure 3: Impulse Response Functions (US Calibration)



To compare the degree of predicted persistence with the data we focus on the autocorrelation functions for inflation and the output gap predicted by the model relative to their empirical counterparts reported by other authors or implied by their results. Key issues are the well known problem of estimating the output gap when potential output is growing over time and how to deal with possible shifts in the mean of inflation across different time periods (Boileau and Letendre, 2003). These arise because the model involves the output gap rather than the level of output and assumes a constant inflation target. Autocorrelations from raw data when such changes have occurred will overestimate the persistence that any model based on the output gap and constant target inflation could match coherently. For example, mean inflation in the US was much higher in the 1970s than the 1990s and hence unadjusted data will show very high correlations between inflation rates over a few quarters. These are standard issues and rather than take a strong stand on the best approach to them we report the results from a number of different approaches. These give a range of possibilities and while more precision would be useful the range is not so wide as to prevent at least a qualitative assessment of closeness to observed persistence.

We chiefly focus on US data. For inflation, Table 2 and Figure 4a show information from Boileau and Letendre (2002, Figure A1; shown by BL in Figures 4a and 5a below), who present autocorrelations of deviations from HP filtered inflation, ii) Soderstrom, Soderlind and Vredin (2002, Table 1; SSV in the figures) who look at raw data for the GDP deflator for 1987-1999 without adjustment on the assumption that the policy regime was stable during this time, and iii) results based on the analysis of Levin and Piger (2003). The latter search for structural breaks in the mean of inflation for the period since the early 1980s, and report the sum of AR coefficients estimated after adjusting for structural breaks if detected. This is done for the four inflation series shown based on the GDP deflator (LP GDP in the figures), CPI (LP CPI), Core CPI (LP Core CPI) and the personal consumption deflator (LP ConDef). The figures shown in Table 2 are derived from Levin and Piger's estimates of the sum of AR coefficients. When the inflation process is AR(1) this is straightforward. When there is a higher order process (Core CPI is AR(5) for example) we derive the autocorrelation function assuming that the AR coefficients decline geometrically. It may be noted that Levin and Piger find a structural break for the GDP deflator within the time period used by Soderstrom, Soderlind and Vredin (2002) so the latter's autocorrelation figures may be high.

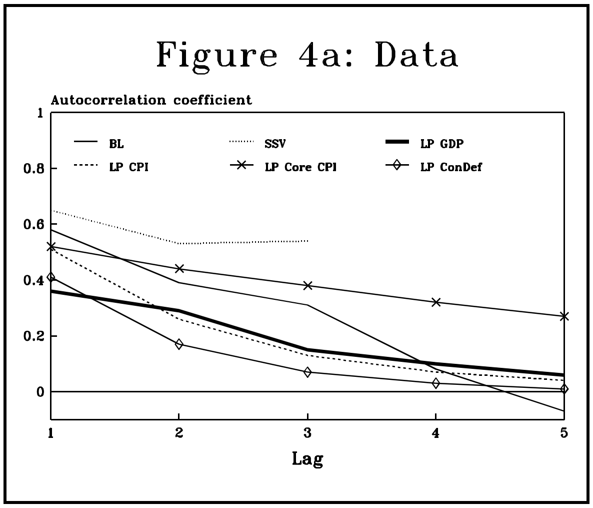
While we do not focus directly on data for the UK and Sweden, Levin and Piger (Figure 4) report similar results for three of the four inflation measures in each case (the common exception being GDP price inflation which shows virtually no persistence after allowing for breaks). Benati (2003) presents similar results for the UK. Batini (2002) reports sums of AR coefficients close to 0.7 for the Euro Area plus France and Italy separately (the results for Germany depend on the data period), which is close to Levin and Piger's figure for US core CPI, though we do not have micro data to calibrate the Phillips curve to see if Euro Area persistence can be matched.

For the output gap, Table 2 and Figure 5a show the autocorrelation functions from, i) Boileau and Letendre (2002, Figure A1) based on deviations from HP filtered US output, ii) Soderstrom, Soderlind and Vredin (2002, Table 1) who use CBO estimates of the output gap, and iii) King and Watson (1996, Table 1b) who use spectral methods to extract output variations at business cycle frequencies.

TABLE 2: AUTOCORRELATION FUNCTIONS.

Variable:	Inflation					Output Gap				
Lag:	1	2	3	4	5	1	2	3	4	5
Data										
Boileau & Letendre	0.58	0.39	0.31	0.08	-0.07	0.85	0.67	0.44	0.20	0.01
Soderstrom et. al.	0.65	0.53	0.54	-	-	0.91	0.83	0.75	-	-
King & Watson	-	-	-	-	-	0.93	0.75	0.50	0.25	0.03
Levin & Piger:										
GDP deflator	0.36	0.29	0.15	0.10	0.06	-	-	-	-	-
CPI	0.51	0.26	0.13	0.07	0.04	-	-	-	-	-
Core CPI	0.52	0.44	0.38	0.32	0.27	-	-	-	-	-
Con. deflator	0.41	0.17	0.07	0.03	0.01	-	-	-	-	-
Simulations: Quarterly inflation targeting, loss function (15)										
1) Calvo	0	0	0	0	0	0	0	0	0	0
2) 2-period Taylor	0.45	-0.05	0.00	0.00	0.00	0.34	-0.04	0.00	0.00	0.00
3) 3-period Taylor	0.46	0.30	-0.11	0.03	-0.01	0.43	0.20	-0.08	0.02	0.00
4) 4-period Taylor	0.43	0.34	0.22	-0.16	0.04	0.44	0.29	0.13	-0.11	0.03
5) 5-period Taylor	0.40	0.34	0.26	0.17	-0.20	0.43	0.33	0.21	0.09	-0.13
6) 6-period Taylor	0.37	0.33	0.27	0.21	0.14	0.42	0.34	0.25	0.15	0.06
New Model:										
7) Wolman	0.46	0.39	0.26	0.14	0.04	0.53	0.40	0.24	0.11	0.01
Flexible prices excluded, Phillips curve (12), price change probabilities from Figure 1b:										
8) US	0.40	0.29	0.15	0.04	0.00	0.44	0.29	0.13	0.03	0.00
9) UK	0.33	0.21	0.11	0.03	0.00	0.36	0.22	0.11	0.02	0.00
10) Sweden	0.46	0.38	0.24	0.09	-0.01	0.52	0.37	0.20	0.06	-0.02
With flexible prices, Phillips curve (14), price change probabilities from Figure 1b:										
11) US	0.43	0.29	0.14	0.04	0.00	0.35	0.26	0.14	0.05	0.00
12) UK	0.35	0.21	0.11	0.03	0.00	0.32	0.19	0.11	0.03	0.01
13) Sweden	0.47	0.36	0.23	0.08	-0.02	0.34	0.28	0.22	0.12	0.00
"Flexible" prices time dependent, price change probabilities from Figure 2b, Phillips curve (12):										
14) US	0.17	0.23	0.12	0.04	0.00	0.21	0.23	0.11	0.03	0.00
15) UK	0.19	0.17	0.10	0.02	0.00	0.23	0.18	0.10	0.02	0.00
16) Sweden	0.27	0.31	0.21	0.08	-0.01	0.35	0.32	0.19	0.06	-0.01
Simulations: Annual inflation targeting, loss function (16)										
17) Calvo	-0.02	-0.01	0.00	0.00	0.00	0.66	0.36	0.12	-0.01	0.00
New Model:										
18) Wolman	0.44	0.37	0.25	0.13	0.03	0.79	0.56	0.34	0.17	0.06
Flexible prices excluded, Phillips curve (12), price change probabilities from Figure 1b:										
19) US	0.36	0.26	0.12	0.03	-0.01	0.75	0.49	0.26	0.10	0.03
20) UK	0.28	0.17	0.09	0.01	-0.01	0.74	0.46	0.23	0.08	0.02
21) Sweden	0.43	0.35	0.22	0.07	-0.02	0.78	0.53	0.30	0.13	0.04
With flexible prices, Phillips curve (14), price change probabilities from Figure 1b:										
22) US	0.32	0.24	0.11	0.03	-0.02	0.81	0.57	0.33	0.13	0.04
23) UK	0.26	0.16	0.08	0.01	-0.01	0.77	0.52	0.28	0.09	0.03
24) Sweden	0.39	0.33	0.20	0.07	-0.03	0.83	0.62	0.39	0.18	0.06
"Flexible" prices time dependent, price change probabilities from Figure 2b, Phillips curve (12):										
25) US	0.11	0.19	0.09	0.02	-0.01	0.74	0.47	0.24	0.09	0.03
26) UK	0.13	0.13	0.07	0.01	0.00	0.72	0.45	0.22	0.07	0.02
27) Sweden	0.23	0.29	0.19	0.07	-0.02	0.77	0.52	0.30	0.13	0.04

Figure 4: Inflation Autocorrelation Functions



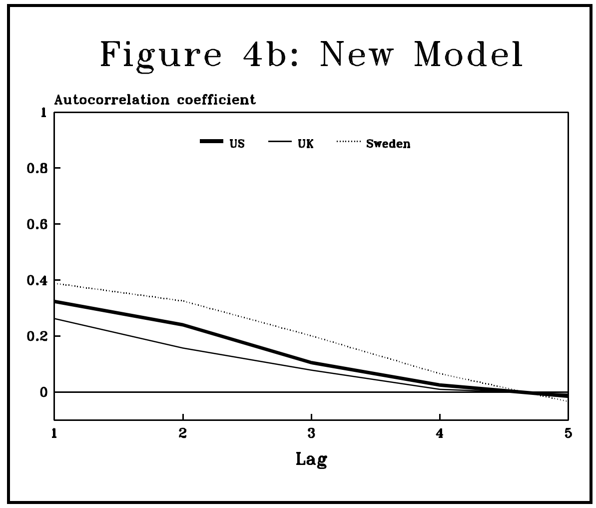
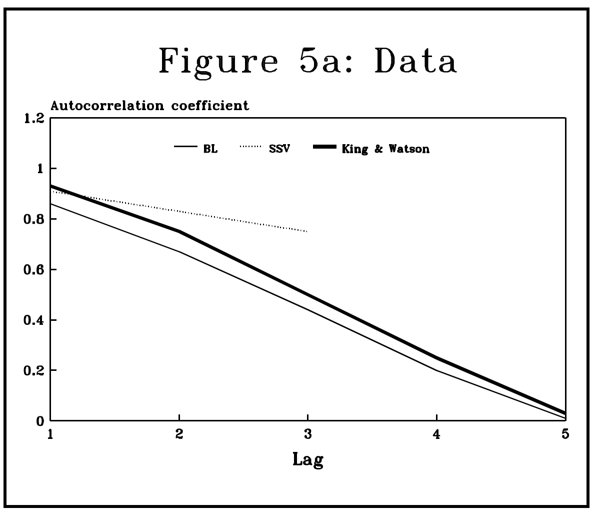
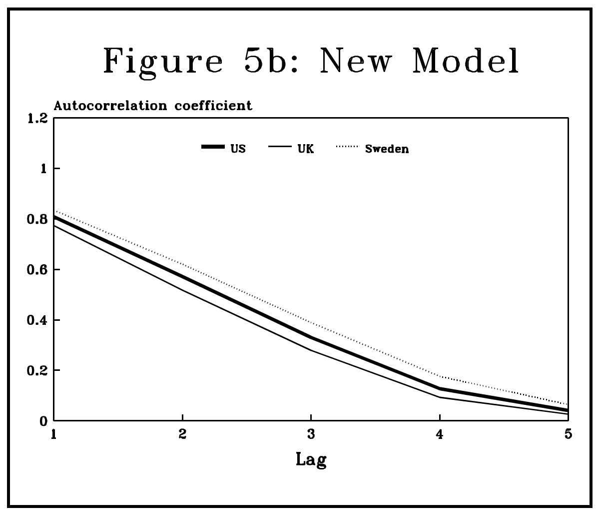


Figure 5: Output Gap Autocorrelation Functions





Before discussing the results for the new model we show for comparison the autocorrelation functions predicted by the Calvo model plus Taylor models of different price durations. We do not show results for the Calvo-Rule of Thumb hybrid model (1) since its ability to predict persistence is well known. Row 1 of Table 2 shows the standard result that for quarterly inflation targeting the

Calvo model predicts no persistence at all given iid shocks. With annual inflation targeting, Row 17 shows that Calvo predicts reasonably strong output gap persistence but with the inflation coefficients becoming slightly negative. Rows 2-6 give results for Taylor models of different durations with quarterly inflation targeting. These show that moving away from Calvo pricing gives rise to persistence, and the autocorrelation coefficients remain positive at longer lags as price duration increases. To calibrate a Taylor type deterministic pricing rule model to the micro data we would need to simulate an aggregate of these cases, with the durations shown in Figure 1a as weights. Partly because the resulting model is much more cumbersome to solve we do not pursue this here but it seems likely that such an aggregate would predict reasonable levels of persistence.

Turning to the new model we discuss the results in Table 2 and those shown in Figures 4b-5b. The main comparison is with US data and thus our core results relate to the US calibrated probabilities of price change shown earlier. However, we also present results for the UK, Sweden and Wolman calibrations both in their own right and as a check on the sensitivity of the simulations to shifts away from the US calibration. As a baseline Rows 7 and 18 show the results using the Wolman probabilities of Figure 1b. These are close to the Levin and Piger results for inflation though the output gap is strongly persistent with annual but not quarterly inflation targeting. For the US, UK and Swedish calibrations our general results are that, i) predicted persistence correlates with the probabilities and duration information in Figures 1-2 with the Swedish data most persistent (longer price durations) and the UK the least, ii) inflation persistence is often close to the data, particularly the Levin and Piger results, under both quarterly and annual inflation targeting, and iii) as with the Wolman case, output persistence is close to the data with annual but not quarterly inflation targeting, though we argued earlier that the former was the preferred specification. At a more detailed level we find little difference between the results when flexible prices are either excluded (Rows 8-10 and 19-21) or included (Rows 11-13 and 22-24). Assuming that these prices are in fact not flexible but part of the time dependent pricing sector changes the time dependent calibration from the micro data. This seems less plausible than assuming flexibility but results in shorter average duration and thus (Rows 14-16 and 25-27) predicted persistence falls, especially for inflation, though it remains positive and higher than the Calvo results.

That case aside, we suggest that the model comes at least close to replicating the persistence in the data. The strength of that conclusion depends in part on which of the data series are given greatest weight, especially for inflation. Nevertheless it should be emphasised that there is a large gap between the predictions of the new calibrated model and the standard Calvo model which also excludes rule of thumb/indexing behaviour. Also while the results differ between the three country calibrations and the Wolman probabilities, the differences are not so large as to make the overall conclusion of reasonable macro data consistency unduly sensitive to the judgements made in Section 1 about the appropriate interpretation of the micro data.

4. Conclusion

An ideal model for monetary policy research would combine fully optimising microfoundations with both macro and micro data consistency. From the micro evidence we followed other authors in questioning the microeconomic realism of Calvo pricing which underpins both the Calvo and Calvo-rule of thumb/indexing models in widespread use. As is well known the well microfounded standard Calvo model has difficulty matching the persistence in macroeconomic data. Its rule of thumb extension is successful in this regard but with a potential sacrifice of optimising microfoundations.

These observations motivated a more careful examination of the microeconomic evidence on price behaviour, especially the age structure of prices rather than simply average price duration, than appears to have been reported previously. In turn this motivated the derivation of a more general model of the Phillips curve than existing forms, a theoretical contribution of the paper which demonstrates the importance of the age structure of prices for that relationship, thus extending the analysis of Wolman (1999), Dotsey (2002) and Kiley (2002). The remainder of the paper explored the implications of the generalised Phillips curve for inflation and output gap persistence when the time dependent pricing rule is calibrated using the micro evidence. We found that the underlying pricing rule matters a lot for predicted dynamics, though without excessive sensitivity to the judgements necessary when interpreting the available micro evidence. In some respects this is a challenging result since it suggests that the convenient simplicity of Calvo pricing may involve a cost in terms of the robustness of results. At the same time the micro calibrated model gave rise to the potentially very significant payoff of much greater consistency with the persistence found in macro data. Hence the new model does well with respect to macro and micro data consistency while retaining fully optimising microfoundations in the standard (Calvo) sense of optimal behaviour for a given pricing rule. In particular the model did not include rule of thumb or indexing behaviour and persistence from serial correlation in the shock process was excluded by assumption. Exactly how close the model comes to matching the macro data depends on the most appropriate interpretations of the macro data itself and, perhaps to a lesser extent, the micro data used for calibration. Both of those are open to debate but on the evidence above the model achieves substantive progress in closing the gap between optimising microfoundations and data consistency, and thus represents a promising extension to our knowledge of models suitable for monetary policy research.

Clearly the analysis could usefully be extended in several directions. Rule of thumb or indexing behaviour could be included if one had a strong prior that it is an important feature of price setting, or more pragmatically if it appeared necessary to further increase predicted persistence. In the latter case the share of rule of thumb firms required to match a given level of persistence would almost certainly be much lower with the micro calibrated pricing rule rather than the Calvo constant probability of price change assumption. The model could also allow for some price setting based on lagged information, together with endogenous capital formation and possibly wage stickiness in addition to price stickiness. More generally it would be highly desirable to have a state dependent pricing model that reproduced the desirable features of the model above. Nevertheless, pending further progress with that approach, virtually all monetary policy research that incorporates nominal stickiness uses time dependent pricing and thus progress within that paradigm is surely useful. On the empirical side the paper took a simple approach to macro data consistency, matching relative inflation/output gap variability but otherwise focussing solely on comparisons between actual and predicted autocorrelation functions. Given that the implications of the micro evidence for predicted macro persistence has received little attention in the literature, a simple approach is informative as a first step but clearly more detailed and formal work could usefully be done.

References

Adam, K. and M. Padula (2003), Inflation dynamics and subjective expectations in the United States, ECB Working Paper No. 222.

Apel, M., R. Friberg and K. Hallsten (2001), Micro foundations of macroeconomic price adjustment: Survey evidence from Swedish firms, Sveriges Riksbank WPS No. 128.

Batini, N. (2002), Euro area inflation persistence, European Central Bank Working Paper 201.

Benati, L. (2003), Evolving Post-World War II UK Economic performance, mimeo, Bank of England.

Bils, M. and P. Klenow (2002), Some evidence on the importance of sticky prices, NBER WP No. 9069.

Blinder, A. S., E. D. Canetti, D. E. Lebow and J. B. Rudd (1998), Asking about prices - A new approach to understanding price stickiness (Russell Sage Foundation, New York).

Boileau, M. and M-A Letendre (2002), Inventories, sticky prices and the propagation of nominal shocks, University of Colorado at Boulder Working Paper No 02-02.

Boileau, M. and M-A Letendre (2003), How much persistence should sticky-price models generate to match US data?, Economics Letters 78, 335-342.

Burstein, A. (2003), Inflation and output dynamics with state dependent pricing decisions, mimeo, University of Michigan.

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 (2003), Nominal rigidities and the dynamic effects of a shock to monetary policy, Revised version of NBER WP No. 8403, 2001; forthcoming, Journal of Political Economy.

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

Dotsey, M. (2002), Pitfalls in interpreting tests of backward-looking pricing in New Keynesian models, Federal Reserve Bank of Richmond Economic Quarterly, Vol. 88/1, Winter 2002.

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.

Dotsey, M. and R. G. King (2001), Pricing, production and persistence, NBER WP No. 8407.

Eichenbaum, M. and J. Fisher (2003), Evaluating the Calvo model of sticky prices, Federal Reserve Bank of Chicago Working Paper 2003-23.

Erceg, C. J. and A. T. Levin (2000), Imperfect credibility and inflation persistence, Journal of Monetary Economics 50(4), May, 915-944.

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

Gali, J. (2003), Interview in "Economic Dynamics", the Society for Economic Dynamics Newsletter Vol. 5, Issue 1, November 2003 (www.economicdynamics.org/News91.htm)

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

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

Hall, S., M. Walsh and A. Yates (2000), Are UK companies' prices sticky?, Oxford Economic Papers 52, 425-446.

Jensen, H. (2002), Targeting nominal income growth or inflation?, American Economic Review 92(4), September, 928-956.

Khan, A., R. G. King and A. L. Wolman (2002), Optimal monetary policy, NBER WP No. 9402.

Kiley, M. T. (2002), Partial adjustment and staggered price setting, Journal of Money, Credit and Banking 34 (2), May, 283-298.

King, R. G. and M. Watson (1996), Money, prices, interest rates and the business cycle, Review of Economics and Statistics 78(1), February, 35-53.

Klaeffing, M. (2003), Monetary policy shocks - A nonfundamental look at the data, ECB Working Paper No. 228.

Levin, A. T., and J. Piger (2003), Is inflation persistence intrinsic to industrial economies?, mimeo, Federal Reserve Board of Governors, April.

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 (2002), Sticky information versus sticky prices: A proposal to replace the New Keynesian Phillips Curve, Quarterly Journal of Economics 117(4), 1295-1328.

Mash, R. (2003a), New Keynesian microfoundations revisited: A Calvo-Taylor-rule of thumb model and optimal monetary policy delegation, Oxford University Department of Economics Discussion Paper No. 174.

Mash, R. (2003b), A note on simple MSV solution methods for rational expectations models of monetary policy, Oxford University Department of Economics Discussion Paper No. 173.

McCallum, B. T. (1999), Issues in the design of monetary policy rules, Chapter 23 in J. B. Taylor and M. Woodford (eds) Handbook of Macroeconomics, Volume 1C (North-Holland)

McCallum, B. T. and E. Nelson (2000), Timeless perspective vs. discretionary monetary policy in forward-looking models, NBER WP 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, Journal of Money, Credit and Banking, forthcoming, (also Sveriges Riksbank WPS No. 119).

Reis, R. (2003), Where is the natural rate? Rational policy mistakes and persistent deviations of inflation from target, Advances in Macroeconomics 3(1), Article 1. http://www.bepress.com/bejm/advances/vol3/iss1/art1

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

Roberts, J. M. (2001), How well does the New Keynesian Sticky Price model fit the data?, Finance and Economics Discussion Series 2001-13, Federal Reserve Board of Governors.

Rudd, J. and K. Whelan (2001), New tests of the New Keynesian Phillips curve, Finance and Economics Discussion Series 2001-30, Federal Reserve Board of Governors.

Rudebusch, G. D. (2002), Assessing nominal income rules for monetary policy with model and data uncertainty, Economic Journal 112(479), April, 402-432.

Sbordone, A. M. (2001), An optimising model of US wage and price dynamics, Working Paper 2001-10, Rutgers University.

Sbordone, A. M. (2002), Prices and unit labour costs: A new test of price stickiness, Journal of Monetary Economics 49(2), 265-292.

Soderstrom, U., P. Soderlind and A. Vredin (2002), Can a calibrated New-Keynesian model of monetary policy fit the facts?, Sveriges Riksbank WPS No. 140.

Steinsson, J. (2003), Optimal monetary policy in an economy with inflation persistence, Journal of Monetary Economics 50(7), October, 1425-1456.

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. (1999), 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. (2003a), Monetary Theory and Policy, 2nd Edition (MIT Press, Cambridge MA).

Walsh, C. E. (2003b), Speed limit policies: The output gap and optimal monetary policy, American Economic Review 93(1), 265-278.

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. (2003), Optimising Models with Nominal Rigidities, Chapter 3 of "Interest and Prices: Foundations of a Theory of Monetary Policy" (Princeton University Press, Princeton)