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ABSTRACT

Can the Facts of UK Inflation Persistence be Explained by Nominal Rigidity?*

It has been widely argued that inflation persistence since WWII has been widespread and durable and that it can only be accounted for by models with a high degree of nominal rigidity. We examine UK post-war data where after confirming previous studies' findings of varying persistence due to changing monetary regimes, we find that models with little nominal rigidity are best equipped to explain it.

JEL Classification: E31 and E37
Keywords: inflation persistence, monetary regime shifts, new classical, New Keynesian and nominal rigidity

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Can the facts of UK inflation persistence be explained by nominal rigidity?[*]

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Abstract

It has been widely argued that inflation persistence since WWII has been widespread and durable and that it can only be accounted for by models with a high degree of nominal rigidity. We examine UK post-war data where after confirming previous studies' findings of varying persistence due to changing monetary regimes, we find that models with little nominal rigidity are best equipped to explain it.

Keywords: inflation persistence, New Keynesian, New Classical, nominal rigidity, monetary regime shifts

JEL Classification: E31, E37

The object of this paper is to ask: how much nominal rigidity does a dynamic stochastic general equilibrium (DSGE) model of the open economy require to account for the inflation persistence we observe in UK data? To do this we first review the facts of UK inflation persistence which have been extensively documented, and find an acceptable time series representation of them. Second we set out the DSGE model with varying degrees of nominal rigidity giving us several alternative versions of it. Finally, we examine how far these various versions of the model can account for the time series representation, using the method of indirect inference; we can then evaluate and rank the success of the various versions in order to answer our question.

1 Related literature

Inflation persistence has been widely noted in the post-war period. Together with other facts of macroeconomic behaviour, notably output persistence, it has motivated the search for dynamic general equilibrium models that could account for such persistence. At the heart of models of this sort in current widespread use is nominal rigidity, or price and inflation stickiness, often modelled by contracts of the sort suggested by Calvo (1983) with a backward-looking element due to indexation (or in some versions rule of thumb behaviour by price setters unable to set their prices optimally). DSGE models with such a Phillips Curve are exemplified by Christiano et al. (2005) and Smets and Wouters (2003); they have been dubbed 'New Keynesian' or 'New NeoKeynesian Synthesis' models. According to this line of theorising inflation persistence can be thought of as largely 'engineered into' the structure of the economy by the specification of the Phillips Curve itself. It should therefore be expected to be fairly constant with little effect from any changes in monetary regime. By contrast there is an alternative line of theorising going back to Lucas (1976) that would argue differently. On this view, inflation persistence is reduced or final form behaviour reflecting the joint behaviour of forcing (error and other exogenous) processes that have natural persistence, a DSGE model with perhaps limited or even no nominal rigidity, and a monetary

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regime that may vary with political choices and perceptions. This final form behaviour will vary with regime and will not necessarily generate high persistence in all regimes.

This difference of approach has spawned a large body of empirical work examining the joint facts of inflation persistence and regime shift. Results have varied widely partly because of the difficulty of pinning down the nature and frequency of regime shifts; in general the more frequent the shifts, the more variable and the lower the persistence found. For the US Pivetta and Reis (2007) show that one can find a case in the univariate inflation data alone for there being constancy of inflation persistence from the 1960s to the present day; thus one cannot reject the null of constancy. Equally they agree that one cannot reject the null of a moderate decline as found by Cogley and Sargent (2002). For the UK a variety of studies have created a consensus that persistence has varied with changes in monetary regime (Batini, 2002, Benati, 2004, Boero, Smith and Wallis, 2007).

From the DSGE side there has also been much work on testing the capacity of various models to mimic among other things the facts of inflation persistence, in the form of the impulse response function of inflation to shocks — for example again Christiano et al. (2005), Smets and Wouters (2003). At this stage the consensus favours the DSGE models with a fair degree of built-in rigidity; but there is still much work to be done.[1]

In particular, most attention has inevitably been paid to the main samples of data used rather than asking whether the models are robust across subsamples. An interesting question that has been largely uninvestigated is whether these models can pick up changes in the impulse response functions that could have been triggered by shifts in monetary regime.

It would clearly be most helpful for the investigation of these issues if one could achieve a reasonable agreement on what monetary regimes were in existence and when. Then one could separate the data into the relevant subsamples and estimate time-invariant time-series processes for each, thus establishing the facts of inflation persistence in each episode. Then also one could modify various contending versions of an appropriate DSGE model and test which of these versions could best account for the facts of each episode. This should enable one to answer the questions; which model version can best explain inflation persistence and are there model versions that cannot explain it at all? While there will still be many other facts that one would like such models to explain and therefore many further fences for these models to fall at, at least we could have made some progress, in a Popperian way (Popper, 1934), in removing some model versions from contention in so far as they fail over inflation persistence.

It turns out that UK data is an answer to this implicit prayer. Whereas it has proved hard to reach agreement on what monetary regimes were in place in the US and indeed whether there was ever any change at all (except briefly at the start of the 1980s with the experiment in the control of bank reserves), for the UK there have been several well-documented changes in monetary regime. Furthermore it is possible, as we will show, to back up the massive documentary evidence econometrically.

Thus in this paper we focus on the phenomenon of inflation persistence in the UK over the post-war period; our aim is to use it to test DSGE models with differing degrees of nominal rigidity. We begin with the facts of regime change, the sine qua non of our methods here. We review the shifts between fixed and floating exchange rates and within the latter between different sorts of monetary and other methods of inflation control. We test our documented split of regimes using a method recently suggested by Qu and Perron (2007) and we find reasonable support for our proposed splits. We are then able to proceed to the next stage which is to estimate the facts of inflation persistence in each episode; we proceed as simply as possible, estimating a parsimonious univariate ARMA for each. As one would expect in such subsamples the inflation process is clearly stationary (a main reason for nonstationarity is after all regime shift); furthermore we know from the DSGE models we set up that the final form of the inflation process will be an ARMA of finite order. We then use the parameters of this ARMA and its implied impulse response function to assess the degree of persistence.

We then turn to the question of how much nominal rigidity is needed to account for the persistence revealed in each episode. We take a standard DSGE model of the open economy with exogenous capital and inject into it different degrees of nominal rigidity; we follow the widely-used procedure of taking a 'stripped down' model, where the Euler equations are converted into a forward-looking IS curve, and the

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[1] Varied microeconomic interpretations have been proposed. Roberts (1998), Ball (2000), Ireland (2000), Mankiw and Reis (2002), Sims (2001) and Woodford (2001) assume that private agents face information-processing constraints. Buiter and Jewitt (1981), Fuhrer and Moore (1995), Fuhrer (2000), Calvo, Celasun and Kumhof (2001), Christiano, Eichenbaum and Evans (2005) assume that high inflation persistence results from the structure of nominal contracts. Others like Rotemberg and Woodford (1997), Dittmar, Gavin and Kydland (2001) and Ireland (2003) generate the persistence through the data generating processes of the structural shocks hitting the economy. However, an alternative view is that the degree of inflation persistence is not an inherent structural characteristic of industrial economies, but in fact a function of the monetary policy regime (see also West, 1988).

remainder of the model consists of the equations for the monetary or other inflation-control regime in place together with the Phillips Curve (and its varying degree of nominal rigidity). We test our different model versions by asking whether each in turn could have generated the patterns of persistence we find in the actual data. To do this we generate the sampling variability within the model under each regime by the method of bootstrapping the model's estimated residuals; this permits us to find the statistical distribution of the $ARMA$ parameters in the inflation regression under the null hypothesis of each model and thus to reject or accept each model. We can also compare the impulse response functions we find in the data with the 95% bounds generated by each model; this test essentially replicates the other one in a more transparent way.

To anticipate our conclusions, first we do not find that inflation persistence is a stylised constant; it appears largely to disappear at various points in the post-war UK, notably most recently; this favours the view that this is indeed connected to several changes in monetary regime, with different regimes exhibiting very different degrees of persistence. Second, we find that while high stickiness can account best for some regimes and low stickiness best for others, the best overall model across all regimes is one with minimum stickiness.

In section 3 therefore we estimate $ARMA$ models for UK data in the various post-war regimes we identify. In section 4 we set out our various models for each monetary regime, calibrate and fit them to the data, to find the implied model errors later to be used in bootstrapping. In section 5 we carry out the bootstrap tests of the models. Section 6 concludes.

2 Estimating UK inflation persistence under changing regimes

Persistence defines the extent to which the effect of a shock persists both in terms of size and length of time; for inflation this effect should be positive, as negative persistence is typically thought of as extreme non-persistence. For a univariate time-series there is no unambiguous scalar measure — see Pivetta and Reis (2007), Phillips (1991), Andrews (1993), Andrews and Chen (2004), Marques (1994), Murray and Papell (2002), Rossi (2001), Hamilton (1994). Matters can be simplified somewhat by assuming an AR process in which case frequently used measures include the sum of the coefficients, the largest root, or the half life (the number of periods for which inflation remains above 0.5 for a unit shock). For an ARMA as assumed here the first two are inappropriate because they ignore the MA coefficients. As we will see below, little hinges on the precise measure used since the impulse response functions (IRFs) estimated are highly transparent and therefore do not require summarising. For completeness we report as summary measures both the half-life and the nearest AR(1) approximation to the IRF.

Over the past decade we have observed substantial shifts in the monetary policy of a number of countries, particularly the widespread adoption of explicit inflation targets. There is a growing body of research supporting the view that the monetary regime in place has an impact on the persistence properties of inflation or in other words inflation persistence is not an inherent characteristic of industrial economies. Brainard and Perry (2000), Taylor (2000) and Kim, Nelson and Piger (2001) have found evidence that US inflation persistence during the Volcker–Greenspan era was substantially lower than during the previous two decades; Ravenna (2000) documents a large post-1990 drop in Canadian inflation persistence; Batini (2002) finds that UK and US inflation had no persistence during the metallic-standard era (prior to 1914), highest persistence during the 1970s and markedly lower persistence during the last decade.

As Nelson (2001) points out, monetary policy in the UK has undergone several regime changes over the last 50 years: from a fixed exchange rate with foreign exchange controls until 1972; to free-floating incomes policy with no domestic nominal anchor until 1978, followed by a system of monetary targeting until the mid-1980s; then back to exchange rate management, the period of 'shadowing' the Deutsche Mark, which culminated in the membership of the Exchange Rate Mechanism (ERM) from 1990-1992; finally since 1992, inflation targeting has been the official regime governing UK monetary policy, with interest rate decisions made by the UK government in collusion with the Bank of England up to May 1997 and after it by the Bank alone, under a new law mandating its procedures and target. Nelson and Nikolov (2004) and Nelson (2007) examine the doctrinal background to these regime shifts.

For the period as a whole, there have been large swings both in inflation and economic growth. Inflation was continuously in double digits during most of the 1970s, and returned there in the early 1980s and 1990s. Nelson (2001) documents that economic growth, which was already lower in the UK in comparison to its major trading partners in the 1960s, underwent a further slowdown after 1973, with partial recovery beginning only in the 1980s. There were recessions in 1972, 1974–75, 1979–81 and

1990–92. However, the disinflation of the early 1990s has been followed by a period of low and stable inflation and reasonably stable real GDP growth.

Plainly, the question of regime breaks is of the utmost importance for our subsequent analysis. Our regime identification is supported by a wealth of narrative evidence (Appendix D). Thus the break-up of Bretton Woods and the UK's shift into floating is a matter of historical record; as were both the introduction of monetary targeting in 1979 and of inflation targeting in 1992. The period of 'exchange rate targeting' from 1986 until the 1992 exit from the ERM is also well documented. Nevertheless, it could be questioned whether there was statistical evidence from the macro time-series supporting the existence of these regime breaks. For this purpose we look at the evidence from the three endogenous macro variables identified in our models: output, inflation and the short-term interest rate. We estimate a VAR in the stationarised values of each viz, Δlog(output), inflation and Δ(interest rate). Using the method of Qu and Perron (2007), we split the sample into three overlapping 20-year sub-samples that each contain two breaks according to our narrative analysis; this split was for computational reasons as running the whole sample in one proved to be too computationally burdensome for the programme to solve. The sub-samples were 1965–85; 1975–95 and 1985–2003. We looked for breaks in both parameters and covariance matrices, with no limit on the number of breaks to be identified. The results are reported in Table 1 which shows when each regime ends and the 95% confidence interval.

		Assumed end of regime	Estimated	95% Confidence Interval	
				Lower	Upper
Bretton Woods	(1965-85)	1970Q4	1972Q1	1971Q4	1975Q1
Incomes Policy	(1965-85)	1978Q4	1981Q2	1977Q4	1981Q3
	(1975-95)	1978Q4	1979Q2	1978Q1	1979Q4
Money Targeting	(1975-95)	1985Q4	1990Q1	1988Q2	1990Q2
	(1985-2003)	1985Q4	1990Q1	1989Q4	1990Q2
Exchange Rate Targeting	(1985-2003)	1992Q3	1993Q4	1992Q4	1994Q2

Table 1: Qu-Perron Structural Break Test

These tests generally confirm the existence of the assumed breaks and place them reasonably close to the assumed break date.[2] They place the end of regimes rather later than we have assumed, in all cases. For Incomes Policy the date lies within the 95% confidence interval and for Exchange Rate Targeting it is within a couple of quarters of it. The main one where the evidence disagrees materially is on the break between Monetary Targeting and Exchange Rate Targeting where it puts it in 1988–1990 against the end of 1985 as assumed here. Thus it confirms the existence of a break from Monetary to Exchange Rate targeting but puts it two years later. Since Inflation targeting starts soon after, this would imply that the Exchange rate targeting regime was rather brief, effectively confined to the period of formal membership of the Exchange Rate Mechanism. On this particular point we decided to allow the narrative evidence to stretch the Exchange Rate targeting sample to include the previous couple of years where there is known to have been 'shadowing' of the ERM, with an expressed target for the sterling-deutschemark rate. In defence of this procedure we would say that when policy regimes change there may well be a lag before agents' behaviour changes; this lag will be the longer when the regime change is not clearly communicated or its effects are not clearly understood. A reasonable case can be made that both with the introduction of both Exchange Rate Targeting and Inflation Targeting this was the case. With the first the switch in policy was deliberately kept unannounced by the Treasury to conceal it from other parts of government (notably 10 Downing Street) which remained attached to Monetary Targeting. With Inflation Targeting the issue was more the sheer unfamiliarity of the regime; only New Zealand had previously adopted it. However we do look at the alternative break points suggested by the Qu-Perron tests in Appendix E as part of our robustness checks; we find that though particular results change they do not affect our conclusions.

Table 2 shows the mean and standard deviation of inflation for the different regimes (annualised quarterly rates of change, in fractions per annum).

The high water mark of inflation both in mean and variance was the Incomes Policy period of the 1970s. This followed the relatively tranquil period of Bretton Woods; and it was in turn followed by

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[2] Benati (2004) finds a similar set of breakpoints using univariate processes for several macro variables as well as frequency domain estimates. The main exception is that we find an additional breakpoint within the 1980-1992 period corresponding to exchange rate targeting.

Regime	Mean	Standard Deviation
Bretton Woods (FUS)	0.036518	0.033962
Incomes Policy (IP)	0.134800	0.081785
Money Targeting (MT)	0.095506	0.073607
Exchange Rate Targeting (FGR)	0.057422	0.042047
Inflation Targeting (IT)	0.024982	0.025131
Full Sample	0.062063	0.064810

Table 2: Summary statistics of inflation (annualised quarterly rates, fractions per annum)

the period of Monetary Targeting when inflation was brought down dramatically. During the Exchange Rate Targeting regime it fell further; this was a period containing a severe recession also. At its end there again followed a period of relative tranquility, under the new Inflation Targeting regime.

The best-fitting ARMA equation for each regime was chosen under the criterion of parsimony. (Notice that Boero et al., 2007, found no evidence of moving variance within similar sub-periods to ours.) Starting with ARMA(1,0) we first raised the order of MA by one and then that of the AR by one, and so on upwards, each time doing an F-test to test (at 99%) whether the more parsimonious model was a valid restriction. The order was raised only if we reject the null hypothesis of a valid restriction. Parsimony increases the power of our tests across DSGE models, possibly at the expense of bias in the estimates of the IRF shape. A further issue that could be raised is our decision to use the quarterly rather than the year-on-year change in prices to model the inflation time-series; sampling error (Shoemaker, 2006) could produce more persistence than could be accounted for by the MA structure in the annual than in the quarterly rate. To check on these issues, we repeated our procedures using time-series forms chosen by Boero et al. (2007) for both annual and quarterly changes — Appendix E, last section. We found no evidence in UK data of the Shoemaker effect; and we also found that our results were robust to Boero et al's quarterly specification.

The F tests can be seen in Table 3, the resulting parameters in Table 4: and the IRFs in Figure 1. In all cases the ARMA was of maximum order two, while in three cases we selected AR(1).

F-Test for Restriction					
	FUS	IP	MT[3]	FGR	IT
ARMA(1,0)→ARMA(1,1)	6.862936*	0.681275	19.298391*	0.003338	0.693967
ARMA(1,0)→ARMA(2,0)	1.282354	0.749222	7.106008*	0.013357	0.332882
ARMA(2,0)→ARMA(2,1)			0.103106		

Table 3: F-Tests to Find Best-Fitting ARMA

Different Monetary Regimes					
	FUS	IP	MT	FGR	IT
AR(1)	−0.592304	0.727366	0.927892	0.623726	0.202142
	(0.138349)	(0.133271)	(0.038179)	(0.164163)	(0.155071)
MA(1)	0.952206		−0.997381		
	(0.066378)		(0.056533)		
$\bar{R}^2$	0.352409	0.565766	0.596308	0.630215	0.697537
S.E. of regression	0.027094	0.053893	0.046768	0.025569	0.013821
AIC	−4.281325	−2.861028	−3.099847	−4.329306	−5.618613
SIC	−4.068176	−2.632006	−2.814374	−4.089336	−5.415864

N.B. Figures in brackets are the standard errors.

Table 4: Best Fitting ARMAs for UK Monetary Policy Regimes

Below the IRFs in Figure **??** we show — where the ARMA order is higher than AR(1) — two summary measures of persistence: the half-life and the closest AR(1) approximation (fitted by OLS to the IRF). Summarising these results, we find very low persistence under Bretton Woods and again under Money Targeting[4] and Inflation Targeting, but the two other regimes exhibit high persistence. We now

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[4] For Monetary Targeting the ARMA(2,2) case which is the next best estimate after the ARMA(2,1) used here suggested

	Half-Life
Bretton Woods	1
Incomes Policy	3
Money Targeting	1
Exchange Rate Targeting	2
Inflation Targeting	1

Table 5: Half-Life of IRFs

turn to the specification and calibration of the New Keynesian and New Classical models within each regime we have identified.

3 Comparing Models and Data using the Bootstrap

3.0.1 The Structural Model — with New Keynesian or New Classical Phillips curve

We now set up simple models with varying price stickiness, derived from micro-foundations in for example the manner of Ireland (1994), Clarida, Gali and Gertler (1999) and McCallum and Nelson (1999, 2000). Appendix C shows the steps in detail, and derives a basic template for each model/regime; the models are based on these and details of their construction are in Appendix D. Here we give a verbal description of what we have done, with a summary of the resulting models. For simplicity we will distinguish between sticky-price 'New Keynesian' models, based on Calvo contracts and flexible-price 'New Classical' models with a simple one-quarter information lag. The root model is identical between New Keynesian and New Classical, apart from the Phillips Curve and the information assumptions (there is an information lag in the New Classical model only). Within the New Keynesian model we will distinguish in turn between three degrees of stickiness: high (with a strong backward-looking element), medium (where backward and forward-looking elements are of similar size) and low (where the forward-looking element is dominant).

In all the models the first equation is the IS curve of the expectational variety that includes $E_t y_{t+1}$ as in Kerr and King (1996), McCallum and Nelson (1997) and Rotemberg and Woodford (1997). This modification imparts a dynamic, forward-looking aspect to saving behaviour and leads to a model of aggregate demand that is tractable and also usable with a wide variety of aggregate supply specifications. This optimising IS function can be regarded as a transformation of the structural consumption Euler equation, with the market-clearing condition for output substituted into it; the error term captures stochastic movements in government spending, exports etc. In the case of the two regimes treated here as having a fixed exchange rate — Bretton Woods and Exchange rate Targeting — we have an additional expenditure switching effect (between the home and foreign goods) in the IS curve.

The second equation in the models is the New Keynesian or New Classical Phillips curve. The former is derived from Calvo contract price-setting with the addition of backward-looking indexation. The latter is the equation of a clearing labour market equating the marginal product of labour with the Euler equation for labour supply, with a one-period information lag among households creating the inflation surprise term.

The last set of equations relate to monetary policy. The Euler equation for household choice of foreign versus home bonds creates the equation of uncovered interest parity (UIP). Under fixed exchange rates, inflation at home changes the real exchange rate and this feeds into net exports and the real interest rate and so the IS curve. Under floating exchange rates the real exchange rate can be substituted out of the IS curve in favour of the real interest rate. We may then identify three variants of policy: one with no nominal anchor and an incomes policy which we model directly, one with monetary targeting and a demand for money, and one with direct setting of interest rates through a Henderson-McKibbin-Taylor rule ('inflation targeting').

3.0.2 Estimating the error processes

In each of the models we estimate the AR coefficients (ρs) of the errors in the IS, Phillips Curve and, where applicable, money supply/demand functions. As the solution itself is a function of the errors, we iterate; we get a first approximation of the errors by using the calibrated parameter values along with the data in the IS/PP curve equation and for the expectational variables the values given by the solution's

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by contrast high persistence. Because this is qualitatively so different we examine in Appendix E from the perspective of robustness how well each model manages to explain it.

lagged terms ignoring the errors. Once we have the shock data we run $AR(1)$ on it, to get our first estimates of these ρs in the various models.

To work out the 'true' errors and ρs we have used a rolling forecast programme. The programme works as follows. Our first estimates of the ρs enable it to work out the expectational variables in the model. Using the expectational variables the model solves for the endogenous variables for the current period and all periods in the future. The new error then is simply the difference between the left hand side and right hand side of the original equation where actual data is plugged in for current and lagged endogenous variables and the expected terms are from the current rolling forecast. Then it estimates $AR(1)$ on these new errors to get the new ρs, which can then be used to work out the new expectational variables. The model then solves again to get the new endogenous variables and then gets yet again a new set of errors. This iterative procedure is repeated until the errors and ρs converge to their 'true' values — as if the expectations that are model derived were used in the first place.

In addition all exogenous variables (foreign interest rate, foreign GDP and foreign prices) have autoregressive processes estimated for them.

4 Bootstrapping and the method of indirect inference

We now replicate the stochastic environment for each model-regime combination to see whether within it our estimated $ARMA$ equations could have been generated. This we do via bootstrapping the models above with their error processes. Meenagh et al. (2008) explain how this procedure is derived from the method of indirect inference[5]. This method uses an 'auxiliary model' to describe the data — such as our time-series representation here — and estimates the parameters of the structural model of interest as those under which this model can replicate the behaviour of the auxiliary model most accurately according to a criterion of 'closeness' — see Gregory and Smith (1991, 1993), Gourieroux et al. (1993), Gourieroux and Monfort (1995) and Canova (2005). The method can also be used to evaluate the closeness of a given model; in effect this arrests the method before estimation proceeds further. This is relevant as here when we are interested in the behaviour of structural models whose structure is rather precisely specified by theory.

The idea of this evaluation is to create pseudo data samples — here 1000 — for inflation. Within each regime we draw the vectors of $i.i.d.$ shocks in our error processes with replacement;[6] we then input them into their error processes and these in turn into the model to solve for the implied path of inflation over the sample period. We then run $ARMA$ regressions on all the pseudo-samples to derive the implied 95% confidence intervals for all the coefficient values found. Finally we compare the $ARMA$ coefficients estimated from the actual data to see whether they lie within these 95% confidence intervals: under the

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[5] The following is adapted from their explanation. Let $x_t(\theta)$ be an $m \times 1$ vector of simulated time series dependent on the $k \times 1$ parameter vector θ and let y_t be the actual data. We assume that $x_t(\theta)$ is generated from a structural model. We assume that there exists a particular value of θ given by θ_0 such that $\{x_t(\theta_0)\}_{s=1}^{S}$ and $\{y_t\}_{t=1}^{T}$ share the same distribution, where $S = cT$ and $c \geq 1$. Thus the null hypothesis is $H_0 : \theta = \theta_0$.

Let the likelihood function defined for $\{y_t\}_{t=1}^{T}$, which is based on the auxiliary model, be $\mathcal{L}_T(y_t; a)$. The maximum likelihood estimator of a is then

$$a_T = \arg\max \mathcal{L}_T(y_t; a)$$

The corresponding likelihood function based on the simulated data $\{x_t(\theta_0)\}_{s=1}^{S}$ is $\mathcal{L}_T[x_t(\theta_0); \alpha]$. Let

$$\alpha_S = \arg\max \mathcal{L}_T[x_t(\theta_0); \alpha]$$

Define the continuous $p \times 1$ vector of functions $g(a_T)$ and $g(\alpha_S)$ and let $G_T(a_T) = \frac{1}{T}\Sigma_{t=1}^{T} g(a_T)$ and $G_S(\alpha_S) = \frac{1}{S}\Sigma_{s=1}^{S} g(\alpha_S)$. We require that $a_T \to \alpha_S$ in probability and that $G_T(a_T) \to G_S(\alpha_S)$ in probability for each θ. If $x_t(\theta)$ and y_t are stationary and ergodic then these hold $a.s.$, see Canova (2005). It then follows that on the null hypothesis, $E[g(a_T) - g(\alpha_S)] = 0$.

Thus, given an auxiliary model and a function of its parameters, we may base our test statistic for evaluating the structural model on the distribution of $g(a_T) - g(\alpha_S)$ using the Wald statistic

$$[g(a_T) - g(\alpha_S)]' W [g(a_T) - g(\alpha_S)]$$

where $W = \Sigma_g^{-1}$ and Σ_g is the covariance matrix of the (quasi) maximum likelihood estimates of $g(\alpha_S)$ which is obtained using a bootstrap simulation. The auxiliary model is a time-series model- here a univariate ARMA- and the function $g(.)$ consists of the impulse response functions of the ARMA. In what follows we specialise the function $g(.)$ to $(.)$;thus we base the test on a_T and a_S, the ARMA parameters themselves.

Non-rejection of the null hypothesis is taken to indicate that the dynamic behaviour of the structural model is not significantly different from that of the actual data. Rejection is taken to imply that the structural model is incorrectly specified. Comparison of the impulse response functions of the actual and simulated data should then reveal in what respects the structural model differs.

[6] By drawing vectors for the same time period we preserve their contemporaneous cross-correlations. The errors also have zero means so that the resulting ARMAs are estimated without a constant, since the true constant must be zero.

null hypothesis of the model-regime being considered, these values represent the sampling variation for the *ARMA* coefficients. We also show a portmanteau Wald statistic, the 95% confidence limit for the joint distribution of the ARMA parameters — Table 6 summarises the results of this exercise. [7]

4.1 Results for the New Classical models:

		Estimated	95% Confidence Interval		Wald
			Lower	Upper	statistic
Bretton Woods	AR(1)	−0.592304	−0.825237	0.930382	67.3
(FUS)	MA(1)	0.952206	−0.969678	1.296733	
Incomes Policy	AR(1)	0.727366	0.199370	0.737302	94.0
(IP)					
Money Targeting	AR(1)	0.927892	−0.801210	0.968120	91.8
(MT)	MA(1)	−0.997381	−0.997490	1.531400	
Exchange Rate Targeting	AR(1)	0.623726	−0.222109	0.258290*	100.0
(FGR)					
Inflation Targeting (RPI)	AR(1)	0.202142	−0.208337	0.294338	79.7
(IT)					

Table 6: Confidence Limits the New Classical Model for Theoretical ARMAs

It can be seen from Table 6 that the model is accepted as a whole (based on the m-metric) for all regimes except for exchange rate targeting where the model falls well short of the estimated persistence.

The charts that follow show the impulse response functions with their 95% confidence intervals. Inflation persistence is fairly low under Bretton Woods; rises as it moves to a floating regime with incomes policy and then falls back sharply under monetary targeting — this was the period of the Thatcher government's 'monetarist' policies designed to squeeze high double-digit inflation out of the economy. Finally persistence rose again under exchange rate targeting until inflation targeting pushed it back down to the Bretton Woods level. The model fails as we have seen to generate enough persistence under exchange rate targeting but otherwise captures the shifts from low to high persistence and then back again to low. As we have seen, this is not because the persistence of the exogenous shocks changes across regimes but rather because the regimes themselves alter the response of inflation to this persistence.

4.2 Results for the New Keynesian models:

We now turn to the New Keynesian versions of the model. In the following tables we show the equivalent bootstrap results. We group them into three: high stickiness (low-ν), medium, and low stickiness (high-ν).

4.2.1 High stickiness (low-ν:)

The model is comprehensively rejected under all regimes (except Incomes Policy which is the same under both models). The reason seems to be the high level of persistence in the New Keynesian Phillips Curve itself, which is both forward-looking as in Calvo and also has a large backward-looking component. This Phillips Curve was constructed to generate persistence: persistence is as it were 'engineered into' the inflation process through it. However, the consequent difficulty is that policy regime changes have insufficient effect on the degree of persistence. Inflation targeting brings it down somewhat; but still nowhere near enough.

These results indicate that the high-stickiness New Keynesian version of the model is rejected for all four regimes (for Incomes Policy, ignored here, it is the same as the New Classical model and accepted). As we saw earlier the NC version was only rejected for Exchange Rate Targeting.

In Appendix C we examine from the model solutions what exactly is driving the differences between the two models. The New Keynesian model fails to fit the varying inflation persistence data essentially

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[7] We may note in passing that this bootstrap distribution of the ARMA parameters is independent of the bootstrap variance of inflation; hence we do not concern ourselves with the extent to which the structural model replicates the variance of the inflation data — in effect we could rescale the model errors to replicate the data variance without affecting this distribution. This results from the fact that ARMA parameters are invariant to scaling of the data in these linearised models. Since we are evaluating our models only on the basis of the ARMA parameters, their ability to match the data variance is therefore not relevant here.

		Estimated	95% Confidence Interval Lower	 Upper	Wald statistic
Bretton Woods	AR(1)	-0.592304	0.651404^*	0.917036	100.0
(FUS)	MA(1)	0.952206	0.014508	0.814515^*	
Money Targeting	AR(1)	0.927892	0.589790	0.972620	99.3
(MT)	MA(1)	-0.997381	0.001890^*	0.997420	
Exchange Rate Targeting (FGR)	AR(1)	0.623726	0.803951^*	0.996775	100.0
Inflation Targeting (RPI) (IT)	AR(1)	0.202142	0.333518^*	0.685009	99.9

Table 7: Confidence Limits from the New Keynesian Model for Theoretical ARMAs

because persistence is 'hard-wired' into its Phillips Curve which contains the high autoregressive root, $1 - \nu$. Without a policy response to inflation, this backward root and the two forward roots (γ and ν) are the roots of the characteristic equation. This backward root can only be reduced by a powerful inflation response from interest rates that changes the configuration of all the roots in the characteristic equation. However, only under inflation targeting does this produce any material reduction and even this is insufficient to match the data. The result is that in all regimes, persistence is excessive compared with the data.

By contrast, the new Classical model derives its inflation persistence properties from the autoregressive roots driving the errors. The monetary policy mechanism can either add further persistent errors or it can offset existing sources of persistence by reacting to an inflation shock with a future inflation reduction (as for example under Inflation targeting).

We can summarise the difference as that persistence in the New Keynesian model is set by the autoregressive roots essentially produced by the Phillips Curve's persistence, which can with difficulty be changed by the monetary regime whereas persistence in the New Classical model is set by the combination of largely fixed autoregressive roots coming from the exogenous processes and of a moving average process much affected by the monetary policy regime.

4.2.2 Medium stickiness (ν: is 0.5)

When the size of the backward-looking root is brought down to around 0.5, the model's implications are for substantially less persistence. This allows it to match the Exchange Rate Targeting regime well. But although it gets closer to the persistence of the Monetary Targeting regime, it is still rejected and is massively rejected for both Bretton Woods and Inflation Targeting.

		Estimated	95% Confidence Interval Lower	 Upper	Wald statistic
Bretton Woods	AR(1)	-0.592304	0.255710^*	0.991510	100.0
(FUS)	MA(1)	0.952206	-0.971190	0.746510^*	
Money Targeting	AR(1)	0.927892	0.050886	0.906435	98.3
(MT)	MA(1)	-0.997381	-0.580258^*	0.970441	
Exchange Rate Targeting (FGR)	AR(1)	0.623726	0.523998	0.845061	63.6
Inflation Targeting (RPI) (IT)	AR(1)	0.202142	0.596853^*	0.819715	100.0

Table 8: Confidence Limits from the New Keynesian Model for Theoretical ARMAs

4.2.3 Low stickiness (ν:=0.9)

In this final version of the New Keynesian model the Phillips Curve is virtually entirely forward-looking, with the least stickiness of any of these Calvo contract models. The model now matches the Money Targeting and Inflation Targeting regimes but it is still too persistent for Bretton Woods and it is now not persistent enough for the Exchange Rate Targeting regime.

		Estimated	95% Confidence Interval		Wald
			Lower	Upper	statistic
Bretton Woods	AR(1)	−0.592304	0.853110*	0.983040	100.0
(FUS)	MA(1)	0.952206	−0.997490	−0.421050*	
Money Targeting	AR(1)	0.927892	0.191180	0.932391	77.3
(MT)	MA(1)	−0.997381	−0.93970*	0.633995	
Exchange Rate Targeting (FGR)	AR(1)	0.623726	−0.274871	0.407777*	100.0
Inflation Targeting (RPI) (IT)	AR(1)	0.202142	−0.247884	0.566936	63.5

Table 9: Confidence Limits from the New Keynesian Model for Theoretical ARMAs

4.3 Comparing the models

The New Keynesian model in its most sticky form generates far too much persistence in all regimes. As the backward-looking root is brought down, it is able to encompass up to two of the regimes only. The persistence features in each case are largely fixed by the Phillips Curve, so that the regime itself has limited influence on the model's overall properties. With the New Classical model where the Phillips Curve itself has merely a one-period information lag, the persistence properties come from the natural autoregressiveness of the errors interacting with the regime. As the regime varies the basic autoregressiveness due to the errors is modified by the regime's responses; this enables the model to encompass most of the variation in persistence across regimes.

Thus if we ask which model version is the most likely, we can measure this by an overall likelihood. In each regime the likelihood of observing the data-generated ARMA parameters, under the null of each model, can be computed from the model's probability density function (we assume this is multi-variate normal by appeal to the central limit theorem since these parameters are sample means). The natural logs of these pdfs are shown in Table 10 together with the sum across all regimes for each model. This last figure represents the log of the joint likelihood.

	Targeting Regimes				
	Bretton Woods	Monetary	Exchange Rate	Inflation	Total
New Keynesian					
High Stickiness	−82.71	−17.94	−6.50	−2.16	−109.31 (−26.6)$^{+}$
Medium Stickiness	−32.16	−10.48	0.86	−9.91	−51.69 (−19.53)$^{+}$
Low Stickiness	$-\infty$	−0.79	−19.10	0.33	$-\infty$ (−19.56)$^{+}$
New Classical	−2.69	−6.44	−7.12	0.45	−15.8 (−13.11)$^{+}$

$^{+}$Numbers in parentheses correspond to the total for the last three regimes

Table 10: Log-likelihood of Observing the Data-Generated ARMA Parameters Under Each Model and Regime

The Table shows that for all the regimes other than for exchange rate targeting the model with least stickiness, the New Classical, is the most likely. This model is also the most likely overall. The carious New Keynesian models perform poorly: the medium stickiness New Keynesian model is the next most likely but it is rejected in three out of the four regimes.

In Appendix E we look at some robustness tests. The most interesting is the one where we substitute the break dates estimated by the Qu-Perron test; in this case we find that the low stickiness version of the New Keynesian model does marginally better than the New Classical; both these models with slight rigidity dominate the other much more rigid New Keynesian models which are both rejected in three out of four regimes..Thus our basic finding that models with low stickiness account for the data the best by a large margin remains robust.

5 Conclusions

UK inflation persistence varies strikingly across the many monetary regimes pursued in the UK during the postwar period. It started low under Bretton Woods, then rose sharply during the next decade as the exchange rate floated without a monetary anchor, fell to virtually nil under the succeeding monetarist regime of the 1980s, before rising again to a high level when the pound was tied to the Deutschemark; finally on the introduction of inflation targeting from 1992 inflation persistence dropped back again to the level last seen under Bretton Woods. These facts cannot be accounted for easily by models of nominal rigidity of the sort modelled in Calvo contracts with a medium to large element of lagged indexation. These models effectively build persistence into the Phillips Curve and this degree of persistence is consequently not at all sensitive to variations in the monetary regime. Thus not surprisingly they find it hard to match the variation of persistence revealed in the facts. By contrast a model with minimal rigidity, such as the flexprice model with a one-quarter information lag, ‘New Classical’ in nature, or the New Keynesian with low stickiness (a very low lagged coefficient) have generally better success in picking up these variations. These models rely for inflation persistence more on the autoregressiveness of the error processes themselves, with different monetary regimes moderating this natural persistence more or less. We conclude in short that inflation persistence is not a constant resulting from the inherent nominal rigidity of the monetary transmission process, but is rather the product of monetary policy interacting with the natural autoregressiveness of exogenous processes and is best captured by models with little nominal rigidity. Of course this leaves various possible future lines of research open. One is whether there is some mechanism that could suitably alter the parameters of the models as regimes change, especially the exogenously imposed degree of stickiness in the New Keynesian models. Another is whether these models can also successfully address other macroeconomic regularities. We hope merely to have established in a Popperian way a negative finding: namely that the facts of UK inflation persistence strongly reject widely-used models with a substantial (fixed) degree of nominal stickiness.

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6 Appendix A: Data

6.1 Data Set (Base year 2000)

1. UK Base Rate: Bank of England Base Rate % (EP). Series UKPRATE. in DataStream.
2. UK Gross Domestic Product: Gross Domestic Product (GDP) at Factor Cost £ millions. Seasonally Adjusted. Series YBHH Table 1.1 Monthly Digest of Statistics.
3. UK M0: Wide Monetary Base. Seasonally Adjusted. Series AVAE Table 6.2 Economic Trends.
4. UK M4: Money Stock. Seasonally Adjusted. Series AUYN Table 6.2 Economic Trends.
5. UK Net Exports: Current Account Balance £ millions, Office of National Statistics (ONS). Series UKHBOG in DataStream. Calculated as fraction of GDP at Factor Cost.
6. UK RPI Price Index: Retail Price Index (RPI), Office of National Statistics (ONS). Not Seasonally Adjusted. Series UKRP....F in DataStream.
7. UK RPIX Price Index : Retail Price Index All items excluding Mortgage Payments, Office of National Statistics (ONS). Not Seasonally Adjusted. Series CHMK Table 3.1 Economic Trends.
8. Sterling/US Dollar: International Financial Statistics for UK. Inverse of Market Rate US Dollars per Pound.
9. Sterling/Deutsche Mark: International Financial Statistics for Germany and UK. Used Market Rate Deutsche Mark per US Dollar and Market Rate US Dollars per Pound to calculate.
10. US Gross Domestic Product: Gross Domestic Product (AR), Bureau of Economic Analysis. Series USGDP...D in DataStream.
11. US Interest Rate: Federal Funds Rate %, Federal Reserve. Series USFEDFUN in DataStream.
12. US Price Index: Consumer Price Index (CPI) All Urban All Items, Bureau of Labour Statistics. Not Seasonally Adjusted. Series USCONPRCF in DataStream.
13. German Gross Domestic Product: Gross Domestic Product, Deutsche Bank. Seasonally Adjusted. Series BDGDP...D in DataStream.
14. German Interest Rate: Day-to-day Money Rate %, Eurostat. Series BDESSFRT in DataStream.
15. German Price Index: Consumer Price Index (CPI), Deutsche Bank. Seasonally Adjusted. Series BDCONPRCE in DataStream.

6.2 Graphs

7 Appendix B: A Basic Open Economy DSGE Model — the derivation from it of the New Keynesian and New Classical models

Consider an economy populated by identical infinitely lived agents who produce a single good as output and use it both for consumption and investment. We assume that there are no market imperfections. We have for ease of argument deleted all shocks from the model but shocks can easily be reintroduced by making various of the fixed parameters stochastic; in principle this will be required as the model is stochastic. At the beginning of each period 't', the representative agent chooses (a) the commodity bundle necessary for consumption, (b) the total amount of leisure that she would like to enjoy, and (c) the total amount of factor inputs necessary to carry out production. All of these choices are constrained by the fixed amount of time available and the aggregate resource constraint that agents face. During the period 't', the model economy is influenced by various random shocks.

In an open economy goods can be traded but for simplicity it is assumed that these do not enter in the production process but are only exchanged as final goods. The consumption, C_t in the utility function below is composite per capita consumption, made up of agents consumption of domestic goods, C_t^d and their consumption of imported goods, C_t^f. We treat the consumption bundle as the numeraire so that all prices are expressed relative to the general price level, P_t. The composite consumption utility index can be represented as an Armington (1969) CES aggregator of the form

$$C_t = \left[\omega\left(C_t^d\right)^{-\rho} + (1-\omega)\left(C_t^f\right)^{-\rho}\right]^{\left(\frac{-1}{\rho}\right)} \tag{1}$$

where ω is the weight of home goods in the consumption function, σ, the elasticity of substitution is equal to $\frac{1}{1+\rho}$.

The consumer maximises this composite utility index, given that an amount $\widetilde{C_t}$ has been chosen for total expenditure, with respect to its components, C_t^d and C_t^f subject to $\widetilde{C_t} = p_t^d C_t^d + Q_t C_t^f$. Where p_t^d is the domestic price level relative to the general price level and Q_t is the foreign price level in domestic currency relative to the general price level (the real exchange rate and also the terms of trade). The resulting expression for the home demand for foreign goods[8] is

$$\frac{C_t^f}{C_t} = [(1-\omega)]^{\sigma}(Q_t)^{-\sigma} \tag{2}$$

We also note that:

$$1 = \omega^{\sigma}\left(p_t^d\right)^{\sigma\rho} + [(1-\omega)]^{\sigma} Q_t^{\sigma\rho} \tag{3}$$

Hence we can obtain the logarithmic approximation:

$$\log p_t^d = -\left(\frac{1-\omega}{\omega}\right)^{\sigma}\log(Q_t) + \text{constant} \tag{4}$$

In a stochastic environment a consumer is expected to maximise expected utility subject to the budget constraint. Each agent's preferences are given by

$$U = MaxE_0\left[\sum_{t=0}^{\infty}\beta^t u\left(C_t, L_t, \frac{M_t}{P_t}\right)\right], \qquad 0 < \beta < 1 \tag{5}$$

---

[8] we form the Lagrangean $L = \left[\omega\left(C_t^d\right)^{-\rho} + (1-\omega)\left(C_t^f\right)^{-\rho}\right]^{\left(\frac{-1}{\rho}\right)} + \mu(\widetilde{C_t} - \frac{P_t^d}{P_t}C_t^d - \frac{P_t^f}{P_t}C_t^f)$..Thus $\frac{\partial L}{\partial \widetilde{C_t}} = \mu$; also at its maximum with the constraint binding $L = \widetilde{C_t}$ so that $\frac{\partial L}{\partial \widetilde{C_t}} = 1$. Thus $\mu = 1$ - the change in the utility index from a one unit rise in consumption is unity. Substituting this into the first order condition $0 = \frac{\partial L}{\partial C_t^f}$. yields equation (2) . $0 = \frac{\partial L}{\partial C_t^d}$. gives the equivalent equation: $\frac{C_t^d}{C_t} = \omega^{\sigma}(p_t^d)^{-\sigma}$ where $p_t^d = \frac{P_t^d}{P_t}$ Divide (1) through by C_t to obtain $1 = \left[\omega\left(\frac{C_t^d}{C_t}\right)^{-\rho} + (1-\omega)\left(\frac{C_t^f}{C_t}\right)^{-\rho}\right]^{\left(\frac{-1}{\rho}\right)}$;substituting into this for $\frac{C_t^f}{C_t}$and $\frac{C_t^d}{C_t}$from the previous two equations gives us equation (3).

where β is the discount factor, C_t is consumption in period 't', L_t is the amount of leisure time consumed in period 't', $\frac{M_t}{P_t}$ is real money balances and E_0 is the mathematical expectations operator. The essential feature of this structure is that the agent's tastes are assumed to be constant over time.

The objective of this paper is to specify a fully articulated model of an open economy which we propose to calibrate/estimate using data for the UK. We use this model to explain the behaviour of real exchange rate and also evaluate the impact of various demand and supply shocks.

7.1 The Representative Household

The model economy is populated by a large number of identical households who make consumption, investment, and labour supply decisions overtime. Each households objective is to choose sequences of consumption and hours of leisure that maximise its expected discounted stream of utility. We assume a time-separable utility function of the form

$$u\left(C_t, 1-N_t, \frac{M_t}{P_t}\right) = \theta \log C_t + (1-\theta)(1-\rho)^{-1}(1-N_t)^{(1-\rho)} + \log \frac{M_t}{P_t} \tag{6}$$

where $0 < \theta < 1$, and $\rho > 0$ is the leisure substitution parameter.

Individual economic agents view themselves as playing a dynamic stochastic game. Changes in expectations about future events would generally affect current decisions. Each agent in our model is endowed with a fixed amount of time which is spent on leisure L_t and/or work N_t. If H_t, total endowment of time is normalised to unity, then it follows that

$$N_t + L_t = 1 \text{ or } L_t = 1 - N_t \tag{7}$$

Furthermore for convenience in the logarithmic transformations we assume that approximately $L = N$ on average.

The representative agent's budget constraint is

$$\frac{M_t}{P_t} + C_t + \frac{b_{t+1}}{1+r_t} + \frac{Q_t b^f_{t+1}}{\left(1+r^f_t\right)} + p_t S^p_t = (1-\tau)\, v_t N_t + b_t + Q_t b^f_t + (p_t + d_t)\, S^p_{t-1} + \frac{M_{t-1}}{P_t} \tag{8}$$

where p_t denotes the real present value of shares, $v_t = \frac{W_t}{P_t}$ is the real consumer wage (w_t, the producer real wage, is the the wage relative to the domestic goods price level; so $v_t = w_t p^d_t$). Labour income is taxed at the rate τ_t, which includes all taxes on households and is assumed to be a stochastic process. b^f_t denotes foreign bonds, b_t domestic bonds, S^p_t demand for domestic shares and $Q_t = \frac{P^f_t}{P_t}$ is the real exchange rate.

In a stochastic environment the representative agent maximizes the expected discounted stream of utility subject to the budget constraint. The first order conditions with respect to C_t, N_t, b_t, b^f_t and S^p_t are:

$$E_0 \beta^t (\frac{M_t}{P_t})^{-1} = E_0 \lambda_t - E_0 \lambda_{t+1} \frac{P_t}{P_{t+1}} \tag{9}$$

$$E_0 \beta^t \theta C_t^{-1} = E_0 \lambda_t \tag{10}$$

$$E_0 (1-\theta)(1-N_t)^{-\rho} = E_0 \lambda_t (1-\tau_t)\, v_t \tag{11}$$

$$E_0 \frac{\lambda_t}{1+r_t} = E_0 \lambda_{t+1} \tag{12}$$

$$E_0 \frac{\lambda_t Q_t}{(1+r^f_t)} = E_0 \lambda_{t+1} Q_{t+1} \tag{13}$$

$$E_0 \lambda_t p_t = E_0 \lambda_{t+1} (p_{t+1} + d_{t+1}) \tag{14}$$

Substituting equation (12) in (10)and letting t=0 yields :

$$(1+r_t) = \left(\frac{1}{\beta}\right) E_t \left(\frac{C_t}{C_{t+1}}\right)^{-1} \tag{15}$$

Now substituting (10) and (12) in (11) yields

$$(1 - N_t) = E_t \left\{ \frac{\theta C_t^{-1} (1 - \tau_t) v_t}{(1 - \theta)} \right\} \tag{16}$$

Substituting out for $v_t = w_t p_t^d$ (and noting that $E_t \log v_t = \log v_t + \log p_t^{ue} = \log w_t + \log p_t^d + \log p_t^{ue}$, where the *ue* superscript means 'unexpected') and using (4) equation (16) becomes

$$(1 - N_t) = \left\{ \frac{\theta C_t^{-1} \left[(1 - \tau_t) \ \ \exp \left(\log w_t - (\tfrac{1-\omega}{\omega})^{\sigma} (\log Q_t) + \log p_t^{ue} \right) \right]}{(1 - \theta)} \right\}^{\frac{-1}{\rho}} \tag{17}$$

Substituting (12) in (14) yields

$$p_t = E_t \left(\frac{p_{t+1} + d_{t+1}}{(1 + r_t)} \right) \tag{18}$$

Using the arbitrage condition and by forward substitution the above yields

$$p_t = E_t \sum_{i=1}^{\infty} \frac{d_{t+i}}{\prod_{j=1}^{i} (1 + r_{t+j})} \tag{19}$$

The above equation states that the present value of a share is simply discounted future dividends.

In small open economy models the domestic real interest rate is equal to the world real interest rate, which is taken as given. Further, it is assumed that the economy has basically no effect on the world rate because, being a small part of the world, its affect on the world savings and investment is negligible. These assumptions imply that the real exchange rate for the small open economy is constant. However, we are modelling a medium sized economy. In our set up the economy is small enough to continue with the assumption that world interest rates are exogenous but large enough for the domestic rate to deviate from the world rate. Hence, in our model real exchange rates are constantly varying.

To derive the uncovered interest parity condition equation (12) is substituted into (13)

$$\left(\frac{1 + r_t}{1 + r_t^f} \right) = E_t \frac{Q_{t+1}}{Q_t} \tag{20}$$

In logs this yields

$$r_t = r_t^f + \log E_t \frac{Q_{t+1}}{Q_t} \tag{21}$$

7.2 The Government

The government finances its expenditure per capita, G_t, by collecting taxes on labour income, τ_t. Also, it issues debt, bonds (b_t) each period which pays a return next period.

The government budget constraint is:

$$G_t + b_t = \tau_t v_t N_t + \frac{b_{t+1}}{1 + r_t} \tag{22}$$

where b_t is real bonds.

7.3 The Representative Firm with fixed capital

Firms rent labour from households, who own their shares,and transform them into output according to a production technology and sell consumption goods to households and government. The technology available to the economy is described by a constant-returns-to scale production function where capital is fixed:

$$Y_t = Z_t {N_t}^{\alpha} \tag{23}$$

where $0 < \alpha < 1$, Y_t is aggregate output per capita and Z_t reflects the state of technology.

In a stochastic environment the firm maximizes present discounted stream, V, of cash flows, subject to the production technology,

$$MaxV = E_t \sum_{i=0}^{T} d^i (Y_{t+i} - w_{t+i} N_{t+i}) \tag{24}$$

Here w_t is the producer real wage. The firm optimally chooses labour so that:

$$N_t = \frac{\alpha Y_t}{w_t} \tag{25}$$

7.4 The Foreign Sector

From equation (2) we can derive the import equation for our economy

$$\log C_t^f = \log IM_t = \sigma \log (1 - \omega) + \log C_t - \sigma \log Q_t \tag{26}$$

Now there exists a corresponding equation for the foreign country which is the export equation for the home economy

$$\log EX_t = \sigma^F \log \left(1 - \omega^F\right) + \log C_t^F + \sigma^F \log Q_t \tag{27}$$

Foreign bonds evolve over time to the balance payments according to the following equation

$$\frac{Q_t b_{t+1}^f}{(1 + r_t^f)} = Q_t b_t^f + p_t^d EX_t - Q_t IM_t \tag{28}$$

7.5 Complete listing:

The above set-up can now be consolidated into a model listing as follows:

Behavioural Equations

(1) Consumption C_t ; solves for r_t:

$$\begin{aligned} (1 + r_t) &= \frac{1}{\beta} E_t \left(\frac{C_t}{C_{t+1}} \right)^{-1} \\ \text{or } C_t &= \gamma C_{t+1} - \delta r_t + c_1 \end{aligned}$$

In this linear, representation we use a first order Taylor series expansion around (average) $\overline{C_t}, \overline{E_t C_{t+1}}$, where $\gamma = \overline{(\frac{C_t}{E_t C_{t+1}})}$ and $\delta = \gamma \beta \overline{C_t}$ and we would typically assume it to be less than unity on the grounds of growth. By dividing both sides by $\overline{C_t}$, we can approximate this linear expression by

$\log C_t = \gamma E_t \log C_{t+1} - \gamma \beta r_t + c_2$

(2) Demand for money: $\log \frac{M_t}{P_t} = E_t \log C_{t+1} - \log \theta - \log(r_t + E_t \pi_{t+1})$

(3) UIP condition:

$$r_t = r_t^F + E_t \log Q_{t+1} - \log Q_t + c_3$$

where r^F is the foreign real interest rate; here we use the property in taking logs that for a lognormal variable $x_t, E_t \log x_{t+1} = \log E_t x_{t+1} - 0.5 \sigma^2_{\log x}$.Thus the constant c_3 contains the variance of $\log C_{t+1}$.

(4) Production function Y_t:

$$\begin{aligned} Y_t &= Z_t (N_t)^\alpha \qquad \text{or} \\ \log Y_t &= \alpha \log N_t + \log Z_t \end{aligned}$$

(5) Demand for labour :

$$\begin{aligned} N_t &= \left(\frac{\alpha Y_t}{w_t} \right) \qquad \text{or} \\ \log N_t &= \log \alpha + \log Y_t - \log w_t \end{aligned}$$

(6) The producer wage is derived by equating demand for labour, N_t, to the supply of labour given by the consumer's first order conditions:

$$\begin{aligned}(1-N_t) &= \left\{\frac{\theta C_t^{-1}\left[(1-\tau_t)\ \ \exp\left(\log w_t - (\frac{1-\omega}{\omega})^{\sigma}(\log Q_t) + \log p_t^{ue}\right)\right]}{(1-\theta)}\right\}^{\frac{-1}{\rho}} \qquad \text{or} \\ \log(1-N_t) &= -\log N_t = c_4 + \frac{1}{\rho}\left[\log C_t - \log(1-\tau_t) - \log w_t - \log p_t^{ue} + (\frac{1-\omega}{\omega})^{\sigma}\log Q_t\right]\end{aligned}$$

where Q_t is the real exchange rate, $(1-\omega)^{\sigma}$ is the weight of domestic prices in the CPI index.

(7) Imports IM_t:

$$\log IM_t = \sigma\log(1-\omega) + \log C_t - \sigma\log Q_t$$

(8) Exports EX_t:

$$\log EX_t = \sigma^F \log\left(1-\omega^F\right) + \log C_t^F + \sigma^F \log Q_t$$

Budget constraints, market-clearing and transversality conditions:

(9) Market-clearing condition for goods:

$$Y_t = C_t + G_t + EX_t - IM_t$$

and we assume the government expenditure share is an exogenous process.

The remainder of the model can be ignored for our purposes.since we are now in a position to derive the various equations of the New Classical model — viz IS, LM, and Phillips Curve. For this purpose we will ignore the constants.

8 Derivation of Small models

The IS curve:

To derive the IS curve note that loglinearising the market-clearing condition directly yields

$$\log Y_t = c\log C_t + g_t + x(\log C_t^F - \log C_t) + x\sigma^* \log Q_t$$

where c is the share of consumption in GDP, x is the share of trade in GDP and $.\sigma^* = \sigma + \sigma^F$. Hence substituting for $\log C_t$ from above yields:

$$\log Y_t = \frac{-(c-x)\gamma\beta}{1-\gamma B^{-1}} r_t + g_t + xC_t^F - x\sigma^* \log Q_t$$

and multiplying through by $1-\gamma B^{-1}$ gives:

$$\log Y_t = -\gamma\beta r_t + \gamma E_t \log Y_{t+1} + (1-\gamma B^{-1})g_t + x(1-\gamma B^{-1})\log C_t^F - x\sigma^*(1-\gamma B^{-1})\log Q_t$$

This is our IS curve.

The LM curve:

To obtain the LM curve we take (2) above and noting that $R_t = r_t + E_t\pi_{t+1}$ obtain:

$$\log M_t - \log P_t = E_t \log C_{t+1} - \log(R_t)$$

Using the loglinearised market-clearing condition above yields

$$E_t \log C_{t+1} = \frac{1}{c-x}(E_t \log Y_{t+1} - E_t g_{t+1} - xE_t \log C_{t+1}^F - x\sigma^* E_t \log Q_{t+1})$$

We now linearise $\log R_t$ around $\overline{R}$ and substitute from the above to obtain:

$$\log(\frac{M_t}{P_t}) = \psi_1 E_t \log Y_{t+1} - \psi_2 R_t + \epsilon_t$$

where $\psi_1 = \frac{1}{c-x}$ and $\psi_2 = \overline{R}^{-1}$

Here the error term $\epsilon_t = \frac{1}{c+x}(-E_t g_{t+1} - xE_t \log C^F_{t+1} - x\sigma^* E_t \log Q_{t+1})$

The New Classical Phillips Curve:

We obtain the New Classical Phillips Curve. We solve the 3 equations production function (4), demand for labour (5), and supply of labour (6), first for expected (equilibrium) values, assuming $\log \mathrm{C}_t$ is also at its expected value. Then we solve the same three equations for the effect of unexpected prices, $\log P^{ue}_t$ (we assume consumption is smoothed to stay at its expected value). From the production function we have $\log Y^{ue}_t = \alpha \log N^{ue}_t$ Hence from the demand for labour we have $\log N^{ue}_t = -\frac{1}{1-\alpha}\log w^{ue}_t$. Finally from the labour supply equation we have $\log N^{ue}_t = \frac{1}{\rho_2}(\log w^{ue}_t + \log P^{ue}_t)$. So it follows that $\log w^{ue}_t$. Finally from the labour supply equation we have $\log w^{ue}_t = \frac{-\rho_2(1-\alpha)}{\rho_2+1-\alpha}(\log P^{ue}_t)$ so that $\log Y^{ue}_t = \frac{\alpha\rho_2}{\rho_2+1-\alpha}(\log P^{ue}_t)$. This is of course the ‘surprise’ Phillips Curve:

$$\log Y_t = \log Y^* + \psi(\log P_t - E_t \log P_t)$$

where it has been assumed that households do not have contemporaneous knowledge of the general price level.

The New Keynesian model:

We may take over all the equations derived above except the surprise Phillips Curve. We now assume that households all have monopoly power in their particular product and set the price in Calvo contracts but with lagged indexation. The resulting pricing equation has been derived carefully in Le and Minford (2006) for price-setting firms with fixed capital and variable labour as

$$\pi_t = \zeta(\log Y_t - \log Y^*) + \nu E_t \pi_{t+1} + (1-\nu)\pi_{t-1}$$

A similar form was derived by Christiano et al. (2005). According to Le and Minford $\nu = \frac{\beta}{1+\beta}$ and should therefore be just below one half. However this formulation assumes that every household indexes prices up by last period’s price; different assumptions on indexation will clearly change the formulation.

The specification effect of Fixed versus floating exchange rates:

Under fixed exchange rates the uncovered interest parity equation ties interest rates to the relevant foreign interest rate while the money supply becomes endogenous and money demand redundant. The real exchange rate is determined by inflation and the relevant exogenous foreign inflation. Thus under fixed rates interest rates are substituted out in favour of exogenous foreign interest rates while the real exchange rate is substituted out by the log of prices and of exogenous foreign prices.

Thus $R_t = R^F_t$; and $\log Q_t = \log P^F_t - \log P_t$. So the IS curve becomes:

$$\begin{aligned}\log Y_t = -\gamma\beta(R^F_t - E_t \log P_{t+1} + E_t \log P_t) + \gamma E_t \log Y_{t+1} + (1-\gamma B^{-1})g_t + x(1-\gamma B^{-1})\log C^F_t \\ + \left[x\sigma^*(1-\gamma B^{-1})\right](\log P^F_t - \log P_t)\end{aligned}$$

where B^{-1} is the forward operator instructing one to lead the variable, holding the date of the expectation constant.

Thus our IS curve under fixed rates becomes:

$$\log Y_t = \gamma E_t \log Y_{t+1} - \phi(1-\gamma^* B^{-1})(\log P_t) - \gamma\beta R^F_t + x(1-\gamma B^{-1})\log C^F_t + [x\sigma^*(1-\gamma B^{-1})]\log P^F_t + v_{FXt}$$

where the error term, v_{FXt}, contains $(1-\gamma B^{-1})g_t$ and any further IS residual; $\gamma^* = \frac{\gamma\beta+\gamma x\sigma^*}{\gamma\beta+x\sigma^*} \prec 1$; and $\phi = \gamma\beta + x\sigma^*$.

Under floating exchange rates uncovered interest parity allows the home interest rate (set by home policy) to determine the real exchange rate (and hence also its expected future value) given exogenous foreign interest rates. Thus we can substitute out the real exchange rate in terms of home and exogenous foreign interest rates. UIP in terms of real interest rates and the real exchange rate yields $(1-B^{-1})\log Q_t = -(r_t - r^F_t)$. Noting that γ is close to unity we may approximate $(1-\gamma B^{-1})\log Q_t$ as $-(r_t - r^F_t)$.and remove $(1-B^{-1})\log Q_t$ from the IS curve in favour of $r_t - r^F_t$, yielding an IS curve under floating rates of:

$$\log Y_t = \gamma E_t \log Y_{t+1} - \phi r_t + v_{FLt}$$

where the error term, v_{FLt}, contains, besides any IS residual, the remaining omitted terms, in this case $(1-\gamma B^{-1})g_t + x(1-\gamma B^{-1})\log C^F_t + x\sigma^* r^F_t$

9 The small models summarised and calibrated

Fixed Exchange Rate model:

$$\text{(IS) } y_t = \gamma E_t y_{t+1} - \phi(1-\gamma^* B^{-1})(\log P_t] - \gamma\beta R_t^F + x(1-\gamma B^{-1})\log C_t^F + [x\sigma^*(1-\gamma B^{-1})]\log P_t^F + v_{FXt}$$

where y_t is detrended log output.

Under Fixed rates the LM curve is redundant. The model is completed by a Phillips Curve, either New Keynesian

$$\pi_t = \zeta(y_t - y^*) + \nu E_t \pi_{t+1} + (1-\nu)\pi_{t-1} + u_{Kt}$$

or New Classical

$$y_t = \delta \log P_t^{ue} + u_{Ct}$$

Floating Exchange rate model:

$$\text{(IS) } y_t = \gamma E_t y_{t+1} - \phi r_t + v_{FLt}$$

Now again there is either a New Keynesian or New Classical Phillips curve as above.

Finally there are differing regimes:

Either Incomes Policy:

$$\text{(IP) } \pi_t = (1-\chi)\pi_{t-1} + c_t$$

Notice that in this regime the Incomes Policy equation bypasses the rest of the model, χ representing the 'toughness' of controls; needless to say such a control regime cannot be expected to last because it could not indefinitely override market forces in the rest of the model; the effect of these is seen in the error term c_t. Nor does it of course, as the regime changes by the end of the decade.

Or Monetary Targeting

$$\text{(MT) } \Delta m_t = m + \mu_t$$

with LM Curve

$$\text{(LM) } m_t - p_t = \psi_1 E_t y_{t+1} - \psi_2 R_t + \epsilon_t$$

where $m_t = \log M_t, p_t = \log P_t$.

Or Inflation Targeting

$$\text{(IT) } R_t = \psi(\pi_t - \pi^*) + i_t$$

Notice here no LM curve is required.

9.1 Calibration and estimation:

9.2 Calibrated and Estimated Parameters of the Models

For δ we took the usual calibration in this literature of 0.2. For other parameters in both models, we took values from Orphanides (1998), Dittmar, Gavin and Kydland (1999), McCallum and Nelson (1999a, 1999b), McCallum (2001), Rudebusch and Svensson (1999), Ball (1999) and Batini and Haldane (1999).

New Classical		New Keynesian	
Parameter	Calibrated Value	Parameter	Calibrated Value
ϕ	0.4	ϕ	0.4; 0.3 (MT)
δ	0.5	ζ	0.2
λ	0.2	λ	0.1 (FUS/FGR);0.17 (MT); 0.3 (IT)
γ	1	γ	0.3/0.7 (FUS/FGR);0.4/0.7 (MT); 0.5/1.0 (IT)*
χ	0.2	ψ_1	0.5
ψ_1	1.0	ψ_2	0.2
ψ_2	0.15	ρ	0.85
ρ	0.85	ψ	1.5
ψ	1.5	ν	0.35(FUS);0.17(MT);0.1(FGR);0.3(IT)$^+$

Table 11: Calibrated Parameters

[*] The first value shown is that used for the high stickiness version. the second for the medium and low stickiness versions.

[+] These values are those used for the high stickiness cases; for medium stickiness the value was 0.5, for low stickiness 0.9 in all regimes.

New Classical

Regime	Estimated AR(1) Parameters of errors and exogenous processes						
	u	v	c	R^F	y^F	P^F	ΔM
Fixed Exchange Rate: US (FUS)	0.521085	0.717961		0.958062	0.833633	1.0	
Incomes Policy (IP)	0.575105	−0.05911	−0.211389				
Money Targeting (MT)	0.345169	0.270198					0.908337
Fixed Exchange Rate: Germany (FGR)	0.650013	0.722195		0.990000	0.478226	1.0	
Inflation Targeting (IT) RPI	0.886310	0.047119					

When the New Keynesian Phillips Curve is substituted for the New Classical, there are now several (two or more) forward roots as well as at least one backward root in each model's characteristic equation (see Appendix C); all must be stable in order for the model to have a stable solution (see Minford and Peel, 2002, chapter 2). This requires numerical analysis: because of the complexity of the equations, it is not possible to establish this analytically in any of these cases. We therefore calibrated each model so that it satisfied this stability condition when subjected to simulation analysis. In general we found this meant keeping the value γ, the forward-looking term in output in the IS curve, somewhat below 1; we have varied it from 1 according to the demands of stability.

Values for ν, the forward-looking root in the Phillips Curve, can also produce a stability problem if close to unity. As it happens the value of this parameter is hotly disputed in recent empirical work. Thus Rudd and Whelan (2005), found the backward element predominant in fitting the inflation data at the single equation level and so set ν close to zero. Gali et al. (2005) on the other hand argue on the basis of their own instrumental variable estimation procedure that it should be close to unity. We decided therefore to look at a range of values for ν.

New Keynesian

Regime	Estimated AR(1) Parameters for errors (same as above for exogenous)	
	u	v
Fixed Exchange Rate: US (FUS)	0.968885	−0.338905
Money Targeting (MT)	0.671948	0.075834
Fixed Exchange Rate: Germany (FGR)	0.911366	−0.730040
Inflation Targeting (IT) RPI	0.502884	−0.392109

Table 12: Estimated Parameters of error processes

10 Appendix C: Solution and analysis of models:

Here we illustrate the solution method with these small models. For simplicity of exposition, we will suppress the exogenous and error processes in the IS curve throughout; and set $m = 0$. The Phillips Curve error (whether New Classical or New Keynesian) is denoted as u_t.

10.1 Incomes Policy:

The solution is straightforwardly obtained by substituting the c_t process.

10.2 New Classical Models:

(a) Fixed rates Here the model is:

$$y_t = \gamma E_t y_{t+1} - \phi(1 - \gamma^* B^{-1})(\log P_t)$$

and

$$y_t = \delta \log P_t^{ue} + u_t$$

We assume here the case where $E_t x_t = E(x_t \mid \Phi_{t-1})$. Let $u_t = \kappa u_{t-1} + \epsilon_t$ or $u_t = \frac{\epsilon_t}{1-\kappa L}$ where L is the lag operator; let $p_t = \log P_t$. The solution is most easily obtained by taking expectations at t of the model and then adding on the unexpected elements of each variable. Taking E_t of the model yields:

$$(1 - \gamma^* B^{-1}) E_t p_t = \phi^{-1}(\gamma B^{-1} - 1) E_t u_t$$

The forward recursion on the error term then yields:

$$E_t p_t = \frac{\phi^{-1}\kappa(\gamma\kappa - 1)}{1 - \gamma^*\kappa} u_{t-1}$$

The unexpected component of prices is:

$$p_t^{ue} = \frac{-1}{\delta + \phi}\epsilon_t$$

so that:

$$p_t = \frac{-1}{\delta + \phi}\epsilon_t - \frac{\phi^{-1}\kappa(1 - \gamma\kappa)}{1 - \gamma^*\kappa} u_{t-1}$$

Multiplying through by $(1 - \kappa L)$ and differencing the equation gives us the inflation solution:

$$\pi_t = \kappa\pi_{t-1} - \varphi_1\epsilon_t + [\varphi_1(1 + \kappa) - \varphi_2]\epsilon_{t-1} + (\varphi_2 - \kappa\varphi_1)\epsilon_{t-2}$$

where $\varphi_1 = (\delta + \phi)^{-1}$ and $\varphi_2 = \frac{\phi^{-1}\kappa(1-\gamma\kappa)}{1-\gamma^*\kappa}$.

The solution in this simplified case where we have only one error is ARMA(1,2). Notice that the sum of the two moving average terms has the value φ_1 which is equal and opposite to the impact effect of the error. Hence the Impulse Response Function has this element working to offset the autoregressive element κ, reducing persistence. In period 2 the response is $\frac{\varphi_2}{\varphi_1} - 1$; in period 3 it is $-(\frac{\varphi_2}{\varphi_1})(1 - \kappa)$; from then on it decays at κ. With our calibration here φ_1 is of order 1 while φ_2 is of order 2κ. Thus in period 2 there is some echo of the impulse but by period 3 it has turned modestly negative

b) Floating rates under Monetary Targeting: Here we have:

$$y_t = \gamma E_t y_{t+1} - \phi r_t$$

$$y_t = \delta p_t^{ue} + u_t$$

and the LM curve

$$m_t - p_t = \psi_1 E_t y_{t+1} - \psi_2 R_t + e_t$$

with money supply process

$$\Delta m_t = \mu_t$$

where $u_t = \frac{\epsilon_t}{1-\kappa L}$ and the money supply error process $\mu_t = \frac{\eta_t}{1-\kappa_1 L}$.

The solution proceeds in the same way, except that now the real interest rate is determined in the money market ($R_t = r_t + E_t p_{t+1} - E_t p_t$). We obtain:

$$\pi_t = \kappa\pi_{t-1} - \varphi_1\epsilon_t + [\varphi_1(1+\kappa) - \varphi_2]\epsilon_{t-1} + [\varphi_2 - \kappa\varphi_1]\epsilon_{t-2} + (1-\kappa L)\frac{[\varphi_3\eta_t + \{\varphi_4 - \varphi_3(1+\kappa_1)\}\eta_{t-1} + \kappa_1\varphi_3\eta_{t-2}]}{1-\kappa_1 L}$$

where

$$\varphi_1 = \frac{\psi_2}{\phi + \delta\psi_2}; \psi = \frac{\psi_2}{1-\psi_2}; \varphi_2 = \frac{\phi\kappa(1-\kappa) + \kappa(\psi_1/\psi_2)}{1-\kappa\psi}; \varphi_3 = \frac{\phi}{\phi + \delta\psi_2}; \varphi_4 = \frac{1}{1-\psi}.$$

Here we find the same pattern as under fixed rates for the IRF of the productivity shock; but now we have in addition the effect of the money shock. If we assume that approximately $\kappa = \kappa_1$, then this adds an MA(2) where since $\varphi_4 > 1 > \varphi_3$ the lagged errors reinforce the effect of lagged inflation. This will mean that this money IRF will have persistence greater than κ;thus in period 1 the value is $\frac{\varphi_4}{\varphi_3} - 1$; in period 2 $\kappa\frac{\varphi_4}{\varphi_3}$; from then decaying at the rate κ. Given that monetary volatility in the UK was high this term is likely to dominate the overall IRF.

c) Floating rates under Inflation Targeting:

Here we have:

$$y_t = \gamma E_t y_{t+1} - \phi r_t$$
$$y_t = \delta p_t^{ue} + u_t$$
$$r_t = -E_t\pi_{t+1} + \psi\pi_t + i_t$$

where $u_t = \frac{\epsilon_t}{1-\kappa L}$ and the monetary error process $i_t = \frac{\eta_t}{1-\kappa_1 L}$. We have also suppressed the lagged interest rate in the targeting equation. The solution is now:

$$\pi_t = \kappa\pi_{t-1} - \varphi_1\epsilon_t + [\varphi_1\kappa - \varphi_2]\epsilon_{t-1} - \frac{(1-\kappa L)}{1-\kappa_1 L}[\varphi_3\eta_t + (\varphi_4 - \kappa_1\varphi_3)\eta_{t-1}]$$

where

$$\varphi_1 = \frac{1}{\delta + \phi\psi}; \varphi_2 = \frac{\kappa(1-\kappa)}{\phi\psi(1-\kappa/\psi)}; \varphi_3 = \frac{\phi}{\delta + \phi\psi}; \varphi_4 = \frac{\kappa_1}{\psi(1-\kappa/\psi)}$$

Let us assume, as occurs in our models, that the inflation response of interest rates,ψ, is fairly large; then both φ_2 and φ_4 will tend to be small. It can then be seen that the MA(1) term in both errors will tend to cancel out the lagged inflation effect, eliminating persistence (assuming as before that $\kappa_1 = \kappa$ approximately).

10.3 New Keynesian Models:

(a) Fixed rates Here we approximate γ^* as unity so that the model can be written conveniently as:

$$y_t = \gamma E_t y_{t+1} + \phi(E_t\pi_{t+1}) \quad \text{(IS)}$$

and

$$\pi_t = \zeta(y_t - y^*) + \nu E_t\pi_{t+1} + (1-\nu)\pi_{t-1} + u_t \quad \text{(Phillips)}$$

We assume here the case where $E_t x_t = E(x_t \mid \Phi_t) = x_t$ (full current information) as is normal in New Keynesian models; $u_t = \frac{\epsilon_t}{1-\kappa L}$ where L is the lag operator.

The solution is obtained directly in terms of forward and backward operators as:

$$(1 - \nu B^{-1} - [1-\nu]L)\pi_t = \frac{\zeta\phi B^{-1}\pi_t}{1-\gamma B^{-1}} + u_t$$

which we can rewrite as:

$$\{\nu\gamma B^{-2} - [\gamma + \nu + (1-\nu)\gamma\nu + \zeta\phi]B^{-1} + [1 + (1-\nu)(\gamma+\nu)] - (1-\nu)L\}\pi_t = (1-\gamma\kappa)u_t$$

We can factor the left hand side to obtain:

$$k(1-\alpha_1 B^{-1})(1-\alpha_2 B^{-1}) : (1-\alpha_3 L)\pi_t = (1-\gamma\kappa)u_t$$

where the roots α_i must all be stable. Note that as $\zeta\phi$ tends to zero these roots are (forward) γ and ν and (backward) $(1-\nu)$. Hence the two backward roots that determine the IRF of the supply shock η_t are κ and $(1-\nu)$; there is no offset from moving average terms. (Moving average terms will be introduced as we introduce other errors; but each of the IRFs of these errors will have the same form considered individually. The MA terms come from their cross-effects which will not alter this basic IRF pattern). The impact effect of η_t is determined by the forward roots so that the overall solution with this one shock is:

$$\pi_t = \left[\frac{1-\gamma\kappa}{k(1-\alpha_1\kappa)(1-\alpha_2\kappa)}\right]\frac{\epsilon_t}{(1-\alpha_3 L)(1-\kappa L)}$$

We can see therefore that under Fixed rates there will be substantial persistence imparted by the backward indexation term in the New Keynesian Phillips Curve as well as the autoregressiveness of the supply shock. Only the terms $\zeta\phi$ can affect the size of the backward root α_3; however it turns out that this tends to raise the value of α_3 in our calibration here where α_3 is barely short of unity.

b) Floating rates under Monetary Targeting: Here we have:

$$y_t = \gamma E_t y_{t+1} - \phi r_t$$

$$\pi_t = \zeta y_t + \nu E_t \pi_{t+1} + (1-\nu)\pi_{t-1} + u_t$$

and the LM curve

$$m_t - p_t = \psi_1 E_t y_{t+1} - \psi_2 R_t + e_t$$

with money supply process

$$\Delta m_t = \mu_t$$

where $u_t = \frac{\epsilon_t}{1-\kappa L}$ and the money supply error process $\mu_t = \frac{\eta_t}{1-\kappa_1 L}$.

The solution proceeds by using the forward and backward operators as above, except that now the real interest rate is determined in the money market ($R_t = r_t + E_t p_{t+1} - E_t p_t$). We obtain:

$$\left((1-L)\{1-(\gamma-\frac{\phi\psi_1}{\psi_2})B^{-1}\}(1-\nu B^{-1}-[1-\nu]L) - \left[\zeta\phi B^{-1} - \zeta\phi(1+\frac{1}{\psi_2})\right]\right)\pi_t$$
$$= (1-L)\{1-(\gamma-\frac{\phi\psi_1}{\psi_2})B^{-1}\}u_t + \frac{\zeta\phi}{\psi_2}\mu_t$$

The LHS of this factorises as in the earlier New Keynesian model into a fourth order difference equation with two forward and two backward roots. As ϕ tends to zero, the backward roots tend to unity and $(1-\nu)$, the forward to γ and ν. However because the supply shock is differenced, the MA process in it cancels out the strong persistence coming from these two backward roots and also from its own autoregressiveness. However this is not true of the monetary growth shock μ_t whose effect will be highly persistent from these two backward roots plus its autoregressiveness.

The only way to bring down this persistence would be for the backward roots to be diminished in size by the effect of the terms in ϕ. However, at least in our calibration here they are increased.

c) Floating rates under Inflation Targeting: Here we have:

$$y_t = \gamma E_t y_{t+1} - \phi r_t$$

$$\pi_t = \zeta y_t + \nu E_t \pi_{t+1} + (1-\nu)\pi_{t-1} + u_t$$

$$r_t = -E_t \pi_{t+1} + \psi\pi_t + i_t$$

Here $u_t = \frac{\epsilon_t}{1-\kappa L}$ and the monetary error process $i_t = \frac{\eta_t}{1-\kappa_1 L}$. We now obtain, following the same operator methods:

$$\left(\{1-\gamma B^{-1}\}(1-\nu B^{-1}-[1-\nu]L) - \zeta\phi B^{-1} + \zeta\phi\psi\right)\pi_t = \{1-\gamma B^{-1}\}u_t - \zeta\phi i_t$$

Here again the LHS factorises into two forward roots and one backward root (which is again tends to $(1-\nu)$ as ϕ tends to zero). Hence the IRFs of both the supply and the monetary shock have their persistence determined by this root and by their own individual autoregressiveness. The only way that this persistence can be reduced is by the terms in ϕ which reflect the strength of the response to higher inflation and its pass-through via the Phillips Curve and the IS curve. In our calibration here we have embodied a high long-run inflation response of interest rates (thus long-run $\psi = 10$). The backward root is approximately halved by this. Hence the Inflation Targeting regime under the New Keynesian model does reduce persistence substantially, though not enough to match the data.

11 Appendix D: The regimes — some historical notes

11.1 Fixed Exchange Rate Regime (US) or Bretton Woods (1956:1 TO 1970:4)

Our first regime is the Bretton Woods fixed exchange rate system. This is not easy to model because of its progressive deterioration in the 1960s when 'one-off' exchange rate changes became commonplace means of adjustment. Another important factor causing change was the progressive dismantling of direct controls — including a relaxation of controls on international capital flows — which, while certainly adding to the potential macro-economic benefits from international economic activity, undoubtedly made fixed exchange rates inherently more difficult to sustain. Furthermore, countries within the system came to attach different priorities to inflation and unemployment as the immediate objective of policy. There was also disagreement about how the burden of domestic policy adjustment should be shared between surplus and deficit countries, including the US, the country of the anchor currency. The system eventually collapsed under the weight of the outflows from the US dollar, which, under the parity system, had to be taken into other countries' official reserves, on such a scale that the dollar's official convertibility into gold had eventually to be formally suspended in 1971.

11.2 Incomes Policy Regime (1971:1 to 1978:4)

Sterling was floated in June 1972.[9] 1972 was also the year of the Heath government's 'U-turn' in macroeconomic policy. The view of the government was that it could stimulate output and employment through expansionary monetary and fiscal policies, while at the same time keeping inflation under control through statutory wage and price controls.[10] The opinion of the day was that the break-out of inflation in the 1970s largely reflected autonomous wage and price movements, and that the appropriate policy response was to take actions that exerted downward pressure on specific products, rather than to concentrate on a monetary policy response. Examples of non-monetary attempts to control inflation included statutory incomes policy announced in November 1972 and the voluntary incomes policy pursued by the Labour government from 1974; the extension of food subsidies in March 1974 budget; and the cuts in indirect taxation in the July 1974 mini-Budget.

From late 1973 policy makers did start paying heed to the growing criticism of rapid money growth that they had permitted. However, there was an unwillingness to make the politically unpopular decision of raising nominal interest rates. The Bank of England was given instructions from the Government that the growth of broad money, the Sterling M3 aggregate, was to be reduced — however, the nominal interest rates must not be increased. The result was the *'Corset,'* the introduction of direct quantitative control on £M3, which imposed heavy marginal reserve requirements if increases in banks' deposits exceeded a limit. While this control did result in a reduction in the observed £M3 growth, it did so largely by encouraging the growth of deposit substitutes, distorting £M3 as a monetary indicator and weakening its relationship with future inflation.[11] For the rest of the 1970s monetary policy often looked restrictive as measured by £M3 growth, but loose as measured by interest rates or monetary base growth.

In July 1976 targets were announced for £M3 monetary aggregate.[12] From then on UK had a monetary policy that reacted to monetary growth and to the exchange rate. Depreciation of the exchange rate in 1976 was a major factor that triggered a tighter monetary policy during 1976-1979. However, we must not over emphasise the monetary tightness as the nominal interest rate was cut aggressively — by

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[9] The float of the exchange rate was announced on the 23 June 1972. See Bank of England (1972).

[10] From 1973 to 1980, the government periodically used the Supplementary Special Deposits Scheme, called the *'Corset,'* as a quantitative control on the expansion of the banks' balance sheets and therefore of the £M3 monetary aggregate.

[11] As Nelson (2000) points out it is likely that this served principally as a device for restricting artificially the measured growth of £M3 without changing the monetary base or interest rates, rather than as a genuinely restrictive monetary policy measure. See also Minford (1993).

[12] The value of this target was 11% from May 1976 to April 1978 and 10% from May 1978 to April 1970. These are the mid-points of the successive targets announced for the annual £M3 growth.

more than 900 basis points from late 1976 to early 1978 — ahead of the fall in inflation from mid-1977 to late 1978. Reflecting the easier monetary policy, money base (£M0) growth, which had been reduced to single digits in the late 1977, rose sharply and peaked at more than 18% in July 1978; inflation troughed at 7.6% in October 1978 and continued to rise until May 1980, when it was 21%. Furthermore, the nominal Treasury bill rate from July 1976 to April 1979 averaged 9.32%. In real terms it was well below zero, indicating the continued tendency of the policy makers until 1978 to hold nominal interest rates well below the actual and prospective inflation rate.[13]

Nelson (2000) finds that the estimated long-run response of the nominal interest rate to inflation was well below unity during the 1970s. Moreover, the real interest rate was permitted to be negative for most of the period. These results suggest that UK monetary policy failed to provide a nominal anchor in the 1970s. However, we note that there was a determinate inflation rate during this period, even though there was clearly no orthodox monetary anchor. What we have chosen to do from a modelling viewpoint is treat Incomes Policy as the determinant of inflation and to assume that interest rates 'fitted in' with what the model dictated was necessary to achieve that inflation rate and the accompanying output rate. Plainly this is a drastic over-simplification since interest rates were independently set at quite inappropriate levels; however, introducing such contradictory monetary policy poses too much of a modelling challenge for this exercise — it could well be that there was such monetary indeterminacy, and incomes policy so incredible, that we were here in a 'non-Ricardian' period where fiscal policy was left to determine inflation. However exploring such possibilities lies well beyond the scope of this chapter.

Thus under Incomes Policy our inflation equation becomes simply: $\pi_t = \chi\pi_{t-1} + c_t$. In this equation, π_t is the inflation quarter-on-quarter annualised and χ is the incomes policy restraint. The equation states that inflation at time t is set by incomes policy at some fraction of the actual inflation in period $t-1$ but subject to an error, the 'break-down' of policy, which we have modelled as an $AR(1)$. During this period there was a serious credibility problem. So, if the government came along and announced that it would cut inflation by 80 percent that simply would not be believable. However, if the government announced that it would cut inflation by say 20 percent then that would definitely be more credible and policy makers would be in a position to gradually get inflation expectations and hence inflation under control. Furthermore, it should be remembered that during this period there were no explicit targets. However, from policymakers' behaviour we do know that there existed implicit targets, and χ helps us operationalise that.

11.3 Money Targeting Regime (1979:1 to 1985:4)

In 1979 inflation was rising rapidly from an initial rate of over 10 percent. The policy of wage controls that had been used to hold down inflation in 1978 had crumbled in the *'winter of discontent'* of that year when graves went undug and rubbish piled up in the streets. The budget was in crisis, the deficit already up to 5 percent of GDP and headed to get worse due to large public sector pay increases promised by the previous government. Milton Friedman (1980) advised a gradual reduction in the money supply growth rate and a cut in taxes in order to stimulate output. The first part was accepted, but the opinion was that tax rates needed to remain high to try and reduce the deficit which was important in conditioning financial confidence.

As mentioned earlier monetary aggregate targeting was introduced in the UK in 1976 in conjunction with the International Monetary Fund (IMF) support arrangement. Figure **??** in the appendix plots the growth of £M0 from 1970 till the end of 2003 and of £M3 from 1979 to 1985. The previous government was quite successful in shrinking the Public Sector Borrowing Requirement (PSBR) from 10 percent in 1975 to less than 4 percent in 1977. However, the policies lacked long-term durability. To achieve durability policy was cast in the form of a Medium Term Financial Strategy (MTFS), a monetary and fiscal policy programme announced by the Conservative Government in its annual budget in 1980. This strategy consisted first of a commitment to a five-year rolling target for gradually decelerating £M3. Second, controls were removed, including the *'Corset'*, exchange controls and incomes policy. Third, the monetary commitment was backed up by a parallel reduction in the PSBR/GDP ratio.

Large misses of the £M3 target were permitted as early as mid-1980, with the MTFS being heavily revised in 1982. In October 1985 £M3 targeting was abandoned. It was however clear prior to the abandonment that key policy makers did not regard overshoots of the £M3 target as intolerable, as long as other measures of monetary conditions, such as interest rates or monetary base growth, were not indicating that monetary policy was loose. Formally, monetary targets continued to be a part of the

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[13] Judd and Rudebusch (1998) report average real interest rate for the US for the period 1970-78 to be 2 basis points. Hence, the phenomenon of low or negative real interest rates in the 1970s was more pronounced in the UK.

MTFS right until 1996. However, by 1988, the targets had been so de-emphasised in monetary policy formation that Nigel Lawson, the Chancellor of the Exchequer could say "As far as monetary policy is concerned, the two things perhaps to look at are the interest rate and the exchange rate."[14]

Even though the logic behind the MTFS was well developed, it failed not only to command credibility, but also to be carried out in its own literal terms. Policy turned out to be more fiercely contractionary than gradualism had intended. As Minford (1993) puts it succinctly "The paradox was: tougher yet less credible policies, apparently the worst of both worlds."

11.4 Exchange Rate Targeting (1986:1 to 1992:3)

The next regime largely consists of informal linking of the Sterling to the Deutsche Mark (DM). This includes not only the *'shadowing'* of the DM in 1986-88, but also the period from autumn 1990 during which UK was a formal member of the Exchange Rate Mechanism (ERM). The idea essentially was that, just as the other major European currencies were successfully aiming to hold inflation down by anchoring their currencies to the DM within the ERM, the UK too could lock in to Germany's enviable record of sustained low inflation even without actually joining the mechanism. The approach was never formally announced, but it became clear in practice that the Sterling/DM exchange rate, which had depreciated very sharply from DM 4 in July 1985 to DM 2.74 in early 1987, was not subsequently allowed to appreciate above DM 3 even though this meant a massive increase in UK foreign exchange reserves, and a reduction of interest rates from 11 percent to a trough of 7 percent during 1987 to prevent the appreciation. This had the effect of accommodating and aggravating the inflationary consequences of the earlier depreciation.

In the Spring of 1988, the exchange rate cap was lifted but by then the boom was already entrenched. Interest rates were pushed up to 15 percent by the Autumn of 1989 to bring the situation under control. A year later the UK also formally joined the ERM. The episode produced a painful recession in which inflation which had risen to over 7% fell back sharply. According to Nelson (2000) from 1987-1990, the Bundesbank's monetary policy, rather than a domestic variable, served as UK monetary policy's nominal anchor.

At the time of ERM entry UK policy needs appeared to coincide with those of its partners. In principle it seemed possible that with the enhanced policy credibility that ERM membership was expected to bring, UK could hope to complete the domestic economic stabilisation programme with lower interest rates than otherwise, and so at less cost in terms of loss of output. There was also a very strong non-monetary consideration, that the UK would have little influence on the outcome of the European Inter-Government Conference if it was not in the ERM.

However, things did not go as planned. German reunification meant that Germany needed to maintain a tight monetary policy at a time when the domestic situation in a number of ERM countries, including the UK, required monetary easing. Parity adjustment was against the ERM rules and seemed inconsistent with maintaining policy credibility. The UK was then confronted with a situation where tightening policy by raising rates made no economic sense in terms of domestic conditions. It then sought to maintain the parity through intervention in the hope that the pressures in Germany would abate. In reality those pressures did not ease soon enough and after heavy intervention, and a last bout of interest rate increases, the UK had no choice but to withdraw from the ERM in September 1992.

The model we use here is the same as the Bretton Woods model with the exception that Germany replaces the US throughout.

11.5 Inflation Targeting Regime (1992:4 to 2003:3)

Immediately following the UK's exit from the Exchange Rate Mechanism (ERM) in September 1992, inflation expectations were between 5 percent and 7 percent at maturities 10 to 20 years ahead — well above the inflation target of 1-4 percent at the time. Five years into the regime, by April 1997, inflation expectations had ratcheted down to just over 4 percent. A credibility gap still remained but it had narrowed markedly. The announcement of operational independence for the Bank of England in May 1997[15] caused a further decline in inflation expectations by around 50 basis points across all maturities. By the end of 1998, inflation expectations were around the UK's 2.5 percent inflation target, at all maturities along the inflation term structure. They have remained at that level since then.

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[14] Testimony, 30 November 1988, in Treasury and Civil Service Committee.

[15] Autonomy of the Bank is enshrined in the Bank of England Act of 1998. This act confers instrument-independence on the Bank, though the government still sets the goals of policy. In the jargon, there is goal-dependence but instrument independence.

Using the inflation target as a reference point for expectations is important during the transition to low inflation as the target then serves as a means of guiding inflation expectations downwards over time. It is widely thought, though not a feature of our models here, that lags in policy mean that inflation-targeting needs to have a forward-looking dimension. According to Haldane (2000) a successful inflation-targeting regime must have *'ghostbusting'* as an underlying theme; by which he means that policy makers take seriously the need to be pre-emptive in setting monetary policy, offsetting incipient inflationary pressures.[16] Nevertheless within our model here a forward element makes no sense and in fact causes indeterminacy; so we have framed interest rate policy in terms of current inflation and output.

12 Appendix E: Sensitivity testing

12.1 A. For the Money Targeting Regime

We investigate two aspects of the Money Targeting regime for sensitivity. The first concerns the ARMA representation. We chose the best which was ARMA(1,1), implying very low persistence. However the next best, and not worse by a large margin, was the ARMA(2,0) which implies high persistence. Thus the MT regime suffers from some ambiguity and we would like to know what difference the alternative would make.

The second aspect concerns the semi-log interest elasticity of demand where we assumed a value of 0.2. This is quite low in the UK context and we consider whether a much higher value (2.0) would alter the results materially.

12.2 The case of an ARMA (2,2)

As one might expect when MT is assessed as having substantial persistence the NC model is no longer able to capture it; it is just rejected because it cannot replicate enough persistence. The NK models with high and medium persistence are also rejected because they generate too much persistence. The NK model with low persistence is now the only one not to be rejected.

		Estimated	95% Confidence Interval		Wald
			Lower	Upper	statistic
New Classical	AR(1)	0.279192	−0.042167	0.664690	99.2
	AR(2)	0.482157	−0.327340	0.351630*	
New Keynesian	AR(1)	0.279192	0.678628	1.860272	98.2
-(High Stickiness)	AR(2)	0.482157	−0.965718	0.205696*	
New Keynesian	AR(1)	0.279192	0.400531*	1.322372	99.0
-(Medium Stickiness)	AR(2)	0.482157	−0.573698	0.189213*	
New Keynesian	AR(1)	0.279192	0.037162	0.923710	67.1
-(Low Stickiness)	AR(2)	0.482157	−0.173640	0.500460	

Table 1: MT ARMA(2,0) Confidence Limits for All Models

Loglikelihoods		Targeting Regimes			
	Bretton Woods	Monetary AR(2)	Exchange Rate	Inflation	Total
New Keynesian					
High Stickiness	−82.71	−7.04	−6.50	−2.16	−98.41(−15.7)$^+$
Medium Stickiness	−32.16	−3.33	0.86	−9.91	−44.54(−12.38)$^+$
Low Stickiness	$-\infty$	0.33	−19.10	0.33	$-\infty$ (−18.44)$^+$
New Classical	−2.69	−1.89	−7.12	0.45	−11.25(−8.56)$^+$

$^+$Numbers in parentheses correspond to the total for the last three regimes

Table 2: MT ARMA(2,0) Log-likelihood of Observing the Data-Generated ARMA Parameters Under Each Model and Regime

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[16] Haldane (2000) goes on to say "*Like ghosts, these pressures will be invisible to the general public at the time policy measures need to be taken. Claims of sightings will be met with widespread derision and disbelief. But the central bank's job is to spot the ghosts and to exorcise them early. A successful monetary policy framework is ultimately one in which the general public is not haunted by inflationary shocks.*"

When one considers the overall rank, nothing really changes.The New Classical remains the least bad, whether considering all regimes or just the last three: though the NC moves from being accepted to rejected at 95% its likelihood increases; this is because with the ARMA(1,1) representation the likelihood function is much flatter — i.e. a much wider combination of parameters is acceptable. This means that the NC is not rejected under ARMA(1,1) but it is also less probable than with the narrower distribution under AR(2).

Furthermore within the NK models the rank also remains the same, with the medium stickiness one better than the low stickiness, again whether under all or only the last three regimes. The reason is the same; that the likelihood of the medium stickiness improves a lot because though rejected in both AR(2) and ARMA(1,1) representations, the distribution under the former is narrower. The improvement for the low stickiness NK model is less because it is closer to the centre of both distributions.

12.3 A higher semi-log interest elasticity of demand for money:

For this sensitivity test we return to the ARMA(1,1) representation. Substituting the much higher interest rate parameter causes instability in the NK model with high stickiness; thus this NK model remains the worst. The other two NK models are not unstable but are badly rejected; the low stickiness does the better of the two. The NC model is accepted easily. The higher elasticity leaves the picture unchanged apart from greatly worsening the behaviour of all the NK models.

		Estimated	95% Confidence Interval		Wald
			Lower	Upper	statistic
New Classical	AR(1)	0.927892	−0.842252	0.810924	52.6
	MA(1)	−0.997381	−1.581487	1.080569	
New Keynesian	AR(1)	0.927892	1.023010	1.043744	100
-(High Stickiness)	MA(1)	−0.997381	0.923299	1.053003	
New Keynesian	AR(1)	0.927892	0.677512	0.761532	100
-(Medium Stickiness)	MA(1)	−0.997381	0.771168	0.997470	
New Keynesian	AR(1)	0.927892	0.835481	0.848542	100
-(Low Stickiness)	MA(1)	−0.997381	−0.997486	−0.286314	

Table 3: MT ARMA(1,1) Confidence Limits for All Models (Higher semi-log interest elasiticity of demand for money)

Loglikelihoods	Targeting Regimes				
	Bretton Woods	Monetary AR(2)	Exchange Rate	Inflation	Total
New Keynesian					
High Stickiness	-82.71	$-\infty$	-6.50	-2.16	$-\infty(-\infty)^+$
Medium Stickiness	-32.16	-326.66	0.86	-9.91	$-367.87(-335.71)^+$
Low Stickiness	$-\infty$	-254.07	-19.10	0.33	$-\infty\ (-272, 84)^+$
New Classical	-2.69	-1.52	-7.12	0.45	$-5.50(-8.19)^+$

$^+$Numbers in parentheses correspond to the total for the last three regimes

Table 4: MT ARMA(2,0) Log-likelihood of Observing the Data-Generated ARMA Parameters Under Each Model and Regime

12.4 Using Regimes Suggested by the Qu-Perron Break Test

The Qu-Perron test suggested that the breaks occured at slightly different times than the ones we assumed. As another sensitivity test we re-estimated the best ARMA for the periods suggested from the Qu-Perron test. The breaks are those estimated in Table 1. Thus we run 'Bretton Woods' up to 1972(1), Incomes Policy up to (1979(2); Monetary Targeting up to 1990(1), Exchange Rate Targeting up to 1993(4) and Inflation Targeting from then on. We found that the best fitting ARMA for the Bretton Woods period changed to ARMA(1,0), Money Targeting changed to ARMA(2,1) and Exchange Rate Targeting to ARMA(1,1). The other two regimes did not change. Below we show the results for estimating these processes on the different models.

12.4.1 FUS(1,0)

		Estimated	95% Confidence Interval		Wald statistic
			Lower	Upper	
New Classical	AR(1)	0.252720	−0.217625	0.221416*	98.6
New Keynesian -(High Stickiness)	AR(1)	0.252720	0.742760*	0.958940	100
New Keynesian -(Medium Stickiness)	AR(1)	0.252720	0.552650*	0.801221	100
New Keynesian -(Low Stickiness)	AR(1)	0.252720	0.593952*	0.809870	100

Table 5: FUS ARMA(1,0) Confidence Limits for All Models (Using Estimated Break Points)

12.4.2 MT(2,1)

		Estimated	95% Confidence Interval		Wald statistic
			Lower	Upper	
New Classical	AR(1)	0.077811	−0.796791	1.214389	84.3
	AR(2)	0.235935	−0.346261	0.425121	
	MA(1)	0.997442	−1.637581	1.604000	
New Keynesian	AR(1)	0.077811	0.045879	1.935800	88.8
-(High Stickiness)	AR(2)	0.235935	−1.025500	0.665230	
	MA(1)	0.997442	−1.308200	0.997470	
New Keynesian	AR(1)	0.077811	−0.141581	1.690976	80.1
-(Medium Stickiness)	AR(2)	0.235935	−0.827722	0.613698	
	MA(1)	0.997442	−1.645538	0.997388*	
New Keynesian	AR(1)	0.077811	−0.153880	1.313200	94.3
-(Low Stickiness)	AR(2)	0.235935	−0.498690	0.774080	
	MA(1)	0.997442	−1.575100	0.997330*	

Table 6: MT ARMA(1,1) Confidence Limits for All Models (Higher semi-log interest elasiticity of demand for money

12.4.3 FGR(1,0)

		Estimated	95% Confidence Interval Lower	 Upper	Wald statistic
New Classical	AR(1)	0.719286	−0.561711	0.648196*	96.3
	MA(1)	−0.997462	−0.959890*	0.997492	
New Keynesian	AR(1)	0.719286	0.734560*	1.002700	100
-(High Stickiness)	MA(1)	−0.997462	−0.223920*	0.944550	
New Keynesian	AR(1)	0.719286	0.045832	1.018915	96.5
-(Medium Stickiness)	MA(1)	−0.997462	−0.997492	0.973976	
New Keynesian	AR(1)	0.719286	−0.906670	0.943330	52.3
-(Low Stickiness)	MA(1)	−0.997462	−0.906670*	1.552300	

Table 7: MT ARMA(1,1) Confidence Limits for All Models (Higher semi-log interest elasiticity of demand for money

Overall, Table 8 shows which model is best using the estimated break points.

			Targeting Regimes		
	Bretton Woods	Monetary	Exchange Rate	Inflation	Total
New Keynesian					
High Stickiness	-27.76	-3.41	-28.28	−2.16	− − 61.62 (−33.86)$^{+}$
Medium Stickiness	-5.65	-3.16	-9.86	−9.91	−28.58 (−22.92)$^{+}$
Low Stickiness	-8.56	-7.12	-1.08	0.33	−16.43 (−7.87)$^{+}$
New Classical	-0.35	-5.84	-14.64	0.45	−20.38 (−20.04)$^{+}$

$^{+}$Numbers in parentheses correspond to the total for the last three regimes

Table 8: MT ARMA(2,0) Log-likelihood of Observing the Data-Generated ARMA Parameters Under Each Model and Regime

In this mutation the low stickiness version of the NK model does best, closely followed by the NC model, whether one considers the likelihood or the number of rejections (1/4 for NKlow, 2/4 for NC). In it we find that the Monetary targeting regime is now classified as high persistence (an AR1 parameter of 0.66), while the much-shortened Exchange Rate Targeting regime becomes low persistence with an AR1 parameter approximation of less than zero.

12.5 Using time-series models estimated by Boero et al. (2007)

Boero et al. (2007) find that over essentially similar regime breaks to ours the following equation fits best for the quarterly inflation rate:

$$\Delta_1 p_t = \alpha_0 + \alpha_1 \Delta_1 p_{t-1} + \alpha_2 \Delta_1 p_{t-2} + \text{seasonal dummies} + \varepsilon_t.$$

They also found no evidence of autoregressive conditional heteroscedasticity. While their purpose was different from ours, namely to investigate changes in inflation volatility, nevertheless they carried out careful searches over a wide variety of time-series specifications, so it is of interest to check whether our results are robust to their alternative autoregressive time-series estimates. We reran their equations over both our chosen break points (‘original breaks’) and those from the Qu and Perron tests (‘QP breaks’). The results are summarised below.

Quarterly, orig. breaks			Targeting Regimes		
	Bretton Woods	Monetary	Exchange Rate	Inflation	Total
AR(1) equivalent*	0.292	0.505	0.611	0.180	
N. K. High Stickiness	−234.5	−5.7	−142.3	−0.9	−383.4
—Medium Stickiness	−17.5	−100.5	1.6+	−5.5	−121.9
—Low Stickiness	−11.3	−0.6+	−0.4	−15.5	−27.8
New Classical	−5.6	1.6+	−8.3	−2.3	−14.6

*the AR(1) that best fits the IRF from the estimated time-series equations +accepted 95%

Table 9: Log-likelihood of Observing the Data-Generated ARMA Parameters Under Each Model and Regime using Boero et al. quarterly Equation and original breakpoints

Quarterly, QP breaks	Targeting Regimes				
	Bretton Woods	Monetary	Exchange Rate	Inflation	Total
AR(1) equivalent*	0.429	0.549	0.722	0.246	
N. K. High Stickiness	−133.0	−5.7	−75.5	0.1	−214.1
—Medium Stickiness	−7.2	−63.6	1.8+	−3.7	−72.7
—Low Stickiness	−3.5	−0.6+	1.9+	−11.7	−14.9
New Classical	−8.7	1.6+	−11.8	−2.4	−21.3

*the AR(1) that best fits the IRF from the estimated time-series equations +accepted 95%

Table 10: Log-likelihood of Observing the Data-Generated ARMA Parameters Under Each Model and Regime using Boero et al. quarterly Equation and QP Breakpoints

We can see from these results that while these equations determine the degree of persistence somewhat differently from others here, it is again the two regimes with little nominal rigidity, New Classical and the New Keynesian with low stickiness, that dominate, with not much to choose between them.

Boero et al. also estimated an equation on annual (year-on-year inflation) data of the form: $\Delta_4 p_t = \beta_0 + \beta_1 \Delta_4 p_{t-1} + \beta_2 \Delta_4 p_{t-2} + \varepsilon_t + \theta \varepsilon_{t-4}$. The suggestion in Shoemaker (2006) was that, because of excess sampling error in the quarterly data, this form could come up with an estimate of persistence higher than one would get purely from the upward bias generated by the moving average element in this form; indicating more genuine persistence than found erroneously in quarterly data. Note that even if there is no persistence at all in the data at a quarterly level, this form will generate a mean estimate of persistence measured by the AR(1) equivalent of around 0.56 and a modal estimate of 0.8 with a 95% confidence interval of 0.03-0.88 (this result was found as the result of bootstrapping a random quarterly inflation series 1000 times, estimating the above equation on it, computing the resulting IRFs for each, and calculating their AR(1) equivalents). The table below shows that the estimated AR(1) equivalents on the actual data are, given the huge imprecision of these estimates, generally not significantly different from our quarterly estimates. The first two exceptions are the monetary targeting regime under both set of breaks; yet here it is higher under the original and lower under the QP breaks, thus there is no systematic evidence that annual data sets persistence higher across these two. The other exception is the exchange rate regime under the original breaks where the annual estimate is lower. Thus overall there is no evidence here that the annual data would yield greater persistence than the quarterly, once adjusted for the moving average bias effect. Indeed it does seem that UK data may well be more homogeneous across sampling points than US data, given the much smaller size of the UK, reducing the size of any effect identified by Shoemaker.

Annual estimates, AR(1) equivalent*	Targeting Regimes			
Orig. breaks	Bretton Woods	Monetary	Exchange Rate	Inflation
AR(1) equivalent* +signific $\succ 0$ at 95%	0.973+	0.970+	0.696	0.639
Quarterly data est of AR(1) equiv., text	0.25	−0.06	0.64	0.20
AR(1) equivalent* mean-bias-adjusted	0.41	0.41x	0.17x	0.08

*the AR(1) that best fits the IRF from the estimated time-series equations x sig. diff. from quarterly at 95%.

Table 11: AR(1) equivalents of Boero et al. annual inflation equation, original breakpoints

Annual estimates, AR(1) equivalent*	Targeting Regimes			
QP breaks	Bretton Woods	Monetary	Exchange Rate	Inflation
AR(1) equivalent* +signific $\succ 0$ at 95%	0.959+	0.569	0.481	0.667
Quarterly data est. of AR(1) equiv., appendix E	0.25	0.66	0.0	0.20
AR(1) equivalent* mean-bias-adjusted	0.40	0.10x	−0.08	0.10

*the AR(1) that best fits the IRF from the estimated time-series equations x sig. diff. from quarterly at 95%

Table 12: AR(1) equivalents of Boero et al. annual inflation equation, QP breakpoints