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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

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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 '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 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 (West, 1988; Ireland, 2003b).

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, 2006, Benati, 2004, Boero, Smith and Wallis, 2009).

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 monetary and other shocks on inflation — 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. Varied microeconomic interpretations have been proposed as the source of this. 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), Smets and Wouters (2003), and Christiano et al. (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 (2003a) generate the persistence through the data generating processes of the structural shocks hitting the economy.

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 stickiness 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 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 inflation 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 2 therefore we estimate $ARMA$ models for UK data in the various post-war regimes we identify. In section 3 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 4 we carry out the bootstrap tests of the models. Section 5 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 — see Brainard and Perry (2000), Taylor (2000) and Kim, Nelson and Piger (2001), Ravenna (2000), Benati (2002) and Levin & Piger (2003).

For the UK in particular, several authors have examined the many shifts in monetary regimes that have occurred — including Nelson (2001), Nelson and Nikolov (2004) and Nelson (2007). 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. However, like the US from the mid-1980s, the UK experienced a 'great moderation' from 1992.

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 (Annex B). Thus the break-up of Bretton Woods (our first regime) and the UK's shift into floating in 1972 is a matter of historical record. There followed what we call the 'incomes policy regime', marked by a monetary and fiscal policy that responded almost exclusively to the levels of output and unemployment; inflation was controlled through episodes of wage/price controls and we model the inflation process directly as a product of these[1]. This period ends in 1979 with the election of a Conservative government committed to monetary targeting. It was clearly not a sustainable regime in the normal sense since it lacked any monetary anchoring of inflation. Since it is not a monetary regime, our models shed no light on it and we will therefore disregard it in our tests of them.

The introduction of monetary targeting in 1979 followed political controversy over the control of inflation. Though the Labour government of James Callaghan had introduced monetary targets in 1976, they were implemented with the help of direct controls on bank deposits and accompanied by wage/price controls because of a lack of faith in the monetary framework among leading Labour ministers. The Conservatives by contrast opposed the use of wage/price controls because they distorted market forces and were in their view ineffective in the long-term control of inflation. Hence the old regime relied on those controls whereas the new regime from 1979 relied exclusively on monetary policy.

The period of 'exchange rate targeting' from 1986 until the 1992 exit from the Exchange Rate Mechanism of the European Monetary System (the ERM) is also well documented. During this period there was disagreement between ministers on how monetary policy should be conducted but informally the Treasury installed an exchange rate target to guide its setting of interest rates — a prodecure known as 'shadowing the Deutschemark'. After the fall of Margaret Thatcher from office in late 1990, the pound formally entered the ERM.

In September 1992 the pound left the ERM under the speculative attack of 'Black Wednesday'. Over the next few months the Treasury and the Bank of England decided to institute the — at that stage relatively new — monetary framework of inflation targeting that had been pioneered by New Zealand. As part of this framework the Bank was made publicly co-responsible for the setting of interest rates and was to publish a regular Inflation Report. Later, when Labour came to power in 1997, the Bank was given sole responsibility for setting interest rates but the framework was otherwise largely unchanged. Thus we treat the whole period from 1992 as a single inflation targeting regime.

Though the narrative evidence is fairly clear-cut, 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.

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.

[1] It is therefore determinate, even if plainly wage/price controls are unsustainable and duly ended in 1979. Clarida et al (2000) suggest for the US that before 1979 a highly accommodative Taylor Rule operated, but such a rule gives an indeterminate solution for inflation. We leave the interesting issue of how exactly to model this regime in terms of monetary (and also fiscal) policy to later work. Here we effectively omit this regime in our comparison of models.

[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

		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

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 (Annex C[3]) 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).

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 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 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. All regressions also contained a constant and three seasonal dummies. (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

to exchange rate targeting.

[3]The annexes can be found at http://www.cf.ac.uk/carbs/faculty/minfordp/

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. (2009) for both annual and quarterly changes — Annex C, 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 — discussed further below.

The F tests can be seen in Table 3[4], 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 * F-test significant+	FUS	IP	MT+	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)		
$\overline{R}^2$	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 1 we show — where the ARMA order is higher than AR(1) — the closest AR(1) approximation (fitted by OLS to the IRF) and also a table of the half-life. Summarising these results, we find very low persistence under Bretton Woods and again under Money Targeting[5] and Inflation Targeting, but the two other regimes exhibit high persistence. We now turn to the specification and calibration of the New Keynesian and New Classical models within each regime we have identified.

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

Table 5: Half-Life of IRFs

[4] For the MT regime the ARMA(1,1), with AIC of −3.099847 and $\overline{R}^2$ of 0.596308, outperformed the ARMA(2,0), with AIC of −2.777950 and $\overline{R}^2$ of 0.443009. We therefore chose it. Nevertheless we also examined later the ARMA(2,0) case because it suggested much greater persistence for this regime.

[5] For Monetary Targeting the ARMA(2,0) case which is the next best estimate after the ARMA(1,1) used here suggested by contrast high persistence. Because this is qualitatively so different we examine later from the perspective of robustness how well each model manages to explain it.

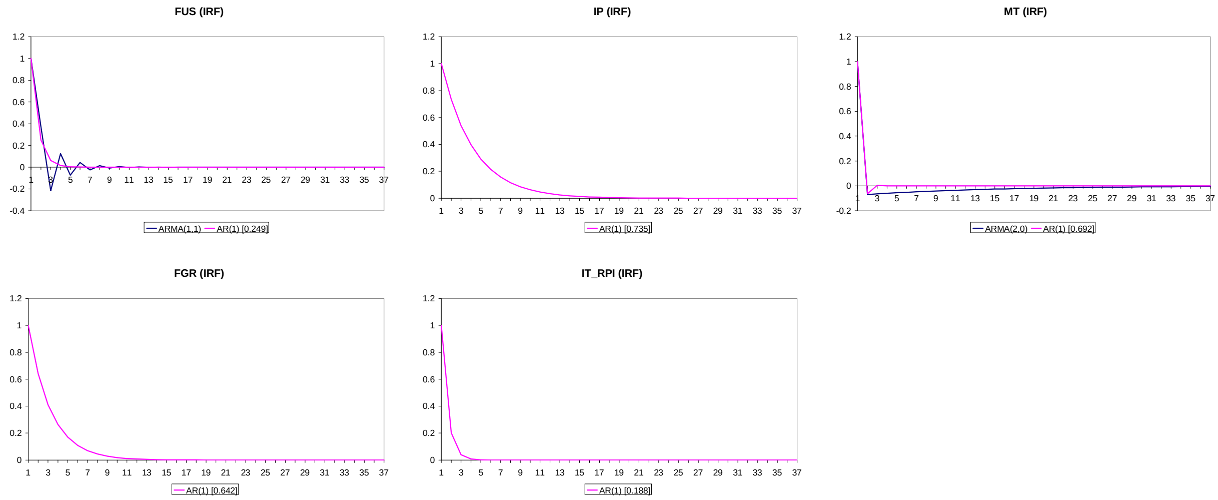

Figure 1: Impulse Response Function (Best-Fitting ARMA, and closest AR(1) representation)

3 Comparing Models and Data using the Bootstrap

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

We now set up simple models with varying inflation stickiness, derived from micro-foundations. In doing this we follow the well-known methods used for example by Clarida, Gali and Gertler (2000) and McCallum and Nelson (1999, 2000) — see Annex A for details in our case. 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; this is needed to give monetary policy an effect on output within a flexible price economy). Within the New Keynesian model we will distinguish in turn between three degrees of inflation 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). All these models assume the high price rigidity of Calvo contracts but they differ in terms of the stickiness of inflation because of the backward-looking indexation component. Only the New Classical model embodies complete price flexibility, with just an information lag to give an element of temporary rigidity.

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, 1999) and Rotemberg and Woodford (1997). 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 two variants of monetary policy: 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'). There is also a regime without any monetary policy, that of 'incomes policy' which we model directly with no input from our structural models here otherwise.

3.1.1 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 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 errors implied by the models and the data, 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 conditional on lagged endogenous and projected exogenous variables[6] 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 we estimate $AR(1)$ on these new errors to get the new ρs, which can then be used to work out the new expectational variables. The model is then solved again to get the new endogenous variables and yet again a new set of errors. This iterative procedure is repeated until the errors and ρs (hence also the expectations) approximately converge.

3.2 The resulting small models

We derive the small models as discussed above; here we set out the equations that emerge and are used for the bootstrapping exercise.

Fixed Exchange Rate model:

$$(\text{IS})y_t = -\phi(R_t - E_t p_{t+1} + p_t) + \gamma E_t y_{t+1} + xNX_t + v_{FXt}$$

where y_t is detrended output, $\phi = \gamma\beta$, $NX_t = (1-\gamma B^{-1})\log C_t^F + \sigma^*(1-\gamma B^{-1})\log Q_t$, $\log Q_t = p_{Ft} - p_t$, $R_t = R_{Ft}$; $R=$ nominal interest rate and $p =$ log of consumer prices. The subscript FX on the error denotes the regime.

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

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

where $\pi_t = \Delta p_t$; the K subscript on the error denotes New Keynesian.

or New Classical (subscript C)

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

where the ue superscript denotes 'unanticipated at t-1'.

Floating Exchange rate model:

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

where as above y_t is detrended output, $\phi = \gamma\beta$, $NX_t = (1-\gamma B^{-1})\log C_t^F + \sigma^*(1-\gamma B^{-1})\log Q_t$, $r_t=$ real interest rate; but now $\log Q_t = E_t \log Q_{t+1} + r_{Ft} - r_t$.

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

[6] In FUS and FGR the foreign interest rate, foreign GDP and foreign prices enter as exogenous variables and have autoregressive processes estimated for them.

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

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

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

Or Inflation Targeting

$$\text{(IT) } R_t = \psi_1(\pi_t - \pi^*) + \psi_2 R_{t-1} + i_t$$

Notice here no LM curve is required.

Calibrated and Estimated Parameters of the Models:

For parameters in both models, we followed 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). The actual parameters used were adjusted to achieve reasonable model properties and so vary across models. In particular 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; 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 and this in turn required a higher ϕ to achieve and adequate long-run effect of real interest rates on aggregate demand.

New Classical

Parameter	Calibrated Value
ϕ	0.1
δ	0.5
λ	0.2
γ	1
χ	0.2
ψ_1	1.0
ψ_2	0.15
ρ	0.85
ψ	1.5

New Keynesian

Parameter	Calibrated Value
ϕ	0.4; 0.3 (MT)
ζ	0.2
λ	0.1 (FUS/FGR);0.17 (MT); 0.3 (IT)
γ	0.3/0.7 (FUS/FGR);0.4/0.7 (MT); 0.5/1.0 (IT)*
ψ_1	0.5
ψ_2	0.2
ρ	0.85
ψ	1.5
ν	0.35(FUS);0.17(MT);0.1(FGR);0.3(IT)+

*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.

Table 6: Calibrated Parameters

The value for ν, the forward-looking root in the Phillips Curve, 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.

The following two tables show the time-series parameters and variances used in bootstrapping the errors; they are the errors implied by the models and the data, and are found as explained in the section above on estimating the error processes.

The residual on interest rate setting in the inflation targeting policy was not bootstrapped, thus being treated as an exogenous process that would have been identical across all models and shocks — perhaps related to other exogenous events such as oil price movements — and not treated as stochastic policy shocks that could have followed a different pattern. The latter would suggest an arbitrariness of policy choice which may be implausible. In this it differs for example from money supply growth, where developments beyond official control will disturb money outcomes.

New Classical				
Regime	Estimated AR(1) Parameters of errors			
	u	v	c	$\mu - \Delta\epsilon_t$
Fixed Exchange Rate: US (FUS)	0.52 (0.000754)	0.72 (0.000262)		
Incomes Policy (IP)	0.58 (0.000935)	−0.06 (0.001576)	−0.21 (0.004800)	
Money Targeting (MT)	0.77 (0.000451)	0.81 (0.001662)		0.88 (0.004672)
Fixed Exchange Rate: Germany (FGR)	0.65 (0.001738)	0.72 (0.000770)		
Inflation Targeting (IT) RPI	0.89 (0.000019)	0.05 (0.000222)		

Table 7: Estimated Parameters and Variances of Error Processes (NC Models) [Variances in parentheses]

New Keynesian			
Regime	Estimated AR(1) Parameters for errors		
	u	v	$\mu - \Delta\epsilon_t$
Fixed Exchange Rate: US (FUS)	0.97 (0.000682)	−0.34 (0.001803)	
Money Targeting (MT)	0.67 (0.004442)	0.08 (0.002706)	0.004 (1.192070)
Fixed Exchange Rate: Germany (FGR)	0.91 (0.001423)	−0.73 (0.002829)	
Inflation Targeting (IT) RPI	0.50 (0.000159)	−0.39 (0.001562)	

Table 8: Estimated Parameters and Variances of Error Processes (NK Models) [Variances in parentheses]

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. 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 fit, here the fit to the ARMA parameters — see Smith (1993), 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 fit 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 (so preserving any cross-correlations between the shocks); 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 (with constants and seasonals suppressed since the shocks have zero mean and no seasonality) 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 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 9 summarises the results of this exercise. This bootstrap distribution of the ARMA parameters, hence of persistence, is independent of the bootstrap variance of inflation; thus we do not concern ourselves with the extent to which the structural model replicates the variance of the inflation data, as our interest here is solely with persistence.

The Wald statistic is derived from the bootstrap distribution of the ARMA parameters under the null hypothesis that the structural model holds. Thus the figures below show, for two parameters in the auxiliary equation such as in an ARMA(1,1), the bootstrap distribution of the parameters under the

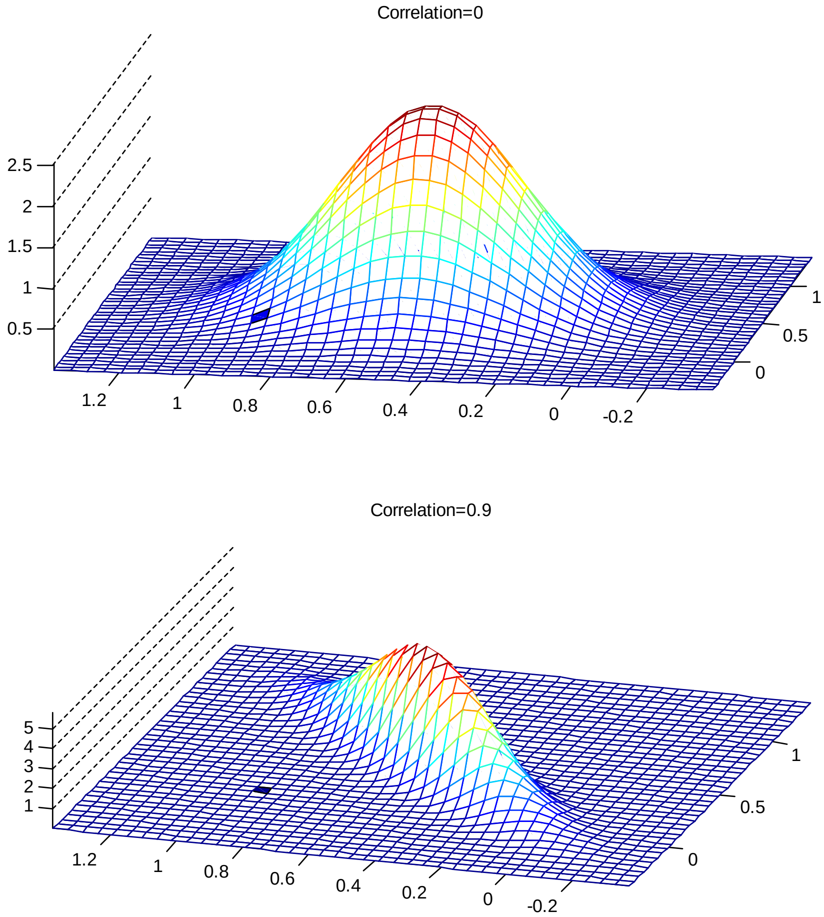

Figure 2: Bivariate Normal Distributions (0.1, 0.9 shaded) with correlation of 0 and 0.9.

null, for two examples, one where the two parameter estimates are uncorrelated, the other where they are highly correlated (0.9). One can think of estimation via indirect inference as changing the parameters of the structural model, thus changing the implied distribution, so as to push the observed data point as far into the centre of the distribution as possible. The test however takes the structural parameters (and hence the bivariate distribution) as given and merely notes the position of the observed data point (here given as 0.1 and 0.9) in the distribution. The Wald statistic is computed as this position expressed as a percentile; thus a percentage for example of 96 indicates that the observed parameter estimates lie on the 96% 'contour', i.e. in the 95% rejection region.

4.1 Results for the New Classical models:

It can be seen from Table 9 that the model is accepted as a whole (based on the Wald statistic) for all regimes except for exchange rate targeting where the model falls well short of the estimated persistence. We include the incomes policy regime here for information, though it is unaffected by the different degrees of rigidity and therefore does not figure in the later comparisons between models.

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

		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 (IP)	AR(1)	0.727366	0.199370	0.737302	94.0
Money Targeting	AR(1)	0.927892	−0.801210	0.968120	91.8
(MT)	MA(1)	−0.997381	−0.997490	1.531400	
Exchange Rate Targeting (FGR)	AR(1)	0.623726	−0.222109	0.258290	100.0
Inflation Targeting (RPI) (IT)	AR(1)	0.202142	−0.208337	0.294338	79.7

Table 9: Confidence Limits the New Classical Model for Theoretical ARMAs

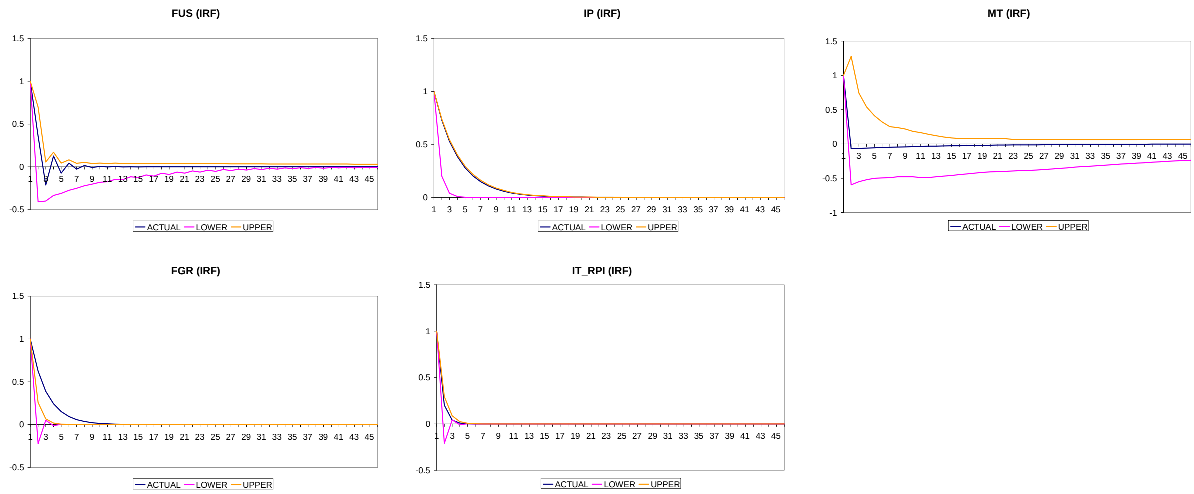

Figure 3: New Classical Impulse Response Functions with 95% Bounds

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 inflation stickiness (low-ν), medium, and low inflation stickiness (high-ν).

4.2.1 High stickiness (low-ν:)

These results indicate that the high-stickiness New Keynesian version of the model is rejected for all four regimes. As we saw earlier the NC version was only rejected for Exchange Rate Targeting. 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 though policy regime changes do have some effect on the degree of persistence, this effect is insufficient to account for the data at least with the calibrations usually used for policy and assumed here. Inflation targeting brings it down materially compared with the other regimes; but still nowhere near enough. By contrast, the New Classical model derives its inflation persistence properties from the autoregressive roots driving the errors as well as the monetary regime to which it is highly sensitive. 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).

		Estimated	95% Confidence Interval Lower	Upper	Wald statistic
Bretton Woods (FUS)	AR(1)	−0.592304	0.651404	0.917036	100.0
	MA(1)	0.952206	0.014508	0.814515	
Money Targeting (MT)	AR(1)	0.927892	0.589790	0.972620	99.3
	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 10: Confidence Limits from the New Keynesian Model for Theoretical ARMAs

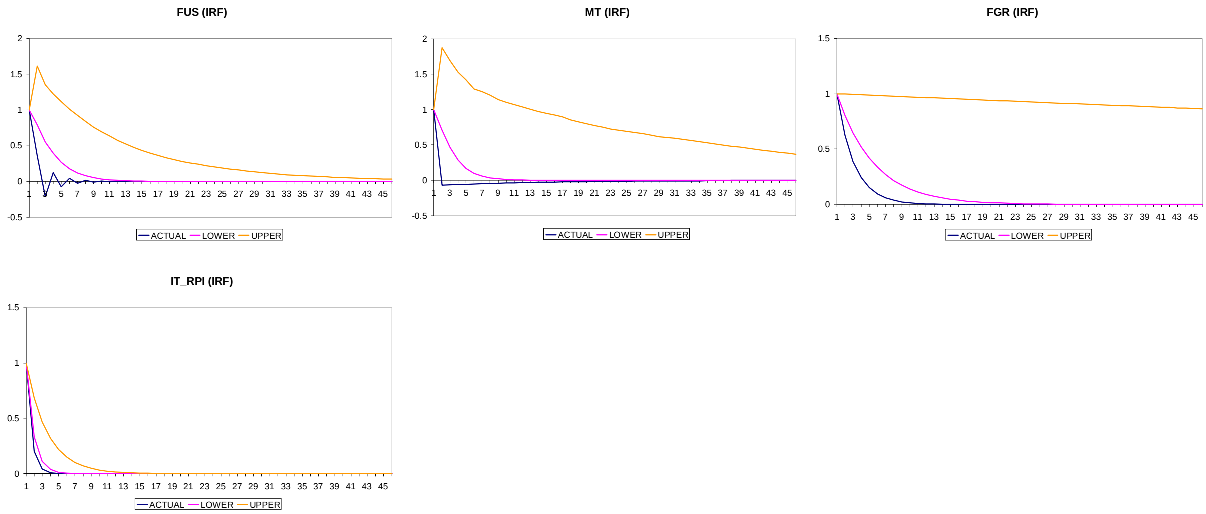

Figure 4: New Keynesian Impulse Response Functions with 95% Bounds (high stickiness)

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.

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 inflation 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 Lower	Upper	Wald statistic
Bretton Woods (FUS)	AR(1)	−0.592304	0.255710	0.991510	100.0
	MA(1)	0.952206	−0.971190	0.746510	
Money Targeting (MT)	AR(1)	0.927892	0.050886	0.906435	98.3
	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 11: Confidence Limits from the New Keynesian Model for Theoretical ARMAs

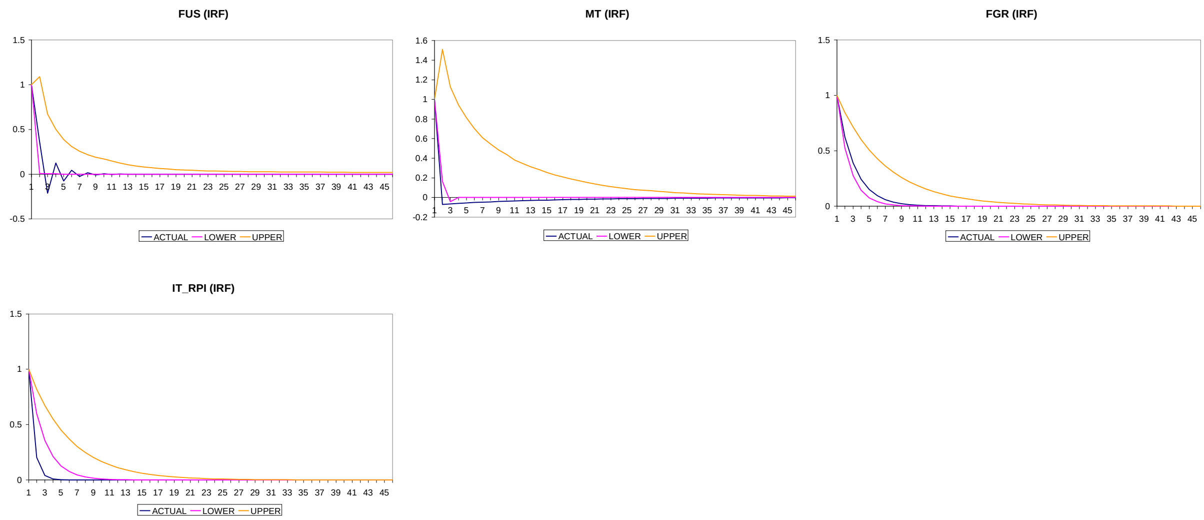

Figure 5: New Keynesian Impulse Response Functions with 95% Bounds (medium stickiness)

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 affected by both the Phillips Curve and the regime itself. The figures below illustrate this for the deterministic IRFs of a supply shock (to the Phillips curve) with an AR(1) coefficient of 0.6. It can be seen for example that under fixed rates for example the high-stickiness case yields extreme persistence but that under strict inflation targeting with a doubled Taylor Rule coefficient on inflation (ITx2) persistence is greatly reduced. 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. Again the figures below show how peristence is reduced as one moves from fixed rates to ITx2.

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 appealling to the central limit theorem since these parameters are sample means). The natural logs of these pdfs are shown in Table 13 together with the sum across all regimes for each model. This last figure represents the log of the joint likelihood.

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 various 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.

		Estimated	95% Confidence Interval Lower	Upper	Wald statistic
Bretton Woods (FUS)	AR(1)	−0.592304	0.853110	0.983040	100.0
	MA(1)	0.952206	−0.997490	−0.42105	
Money Targeting (MT)	AR(1)	0.927892	0.191180	0.932391	77.3
	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 12: Confidence Limits from the New Keynesian Model for Theoretical ARMAs

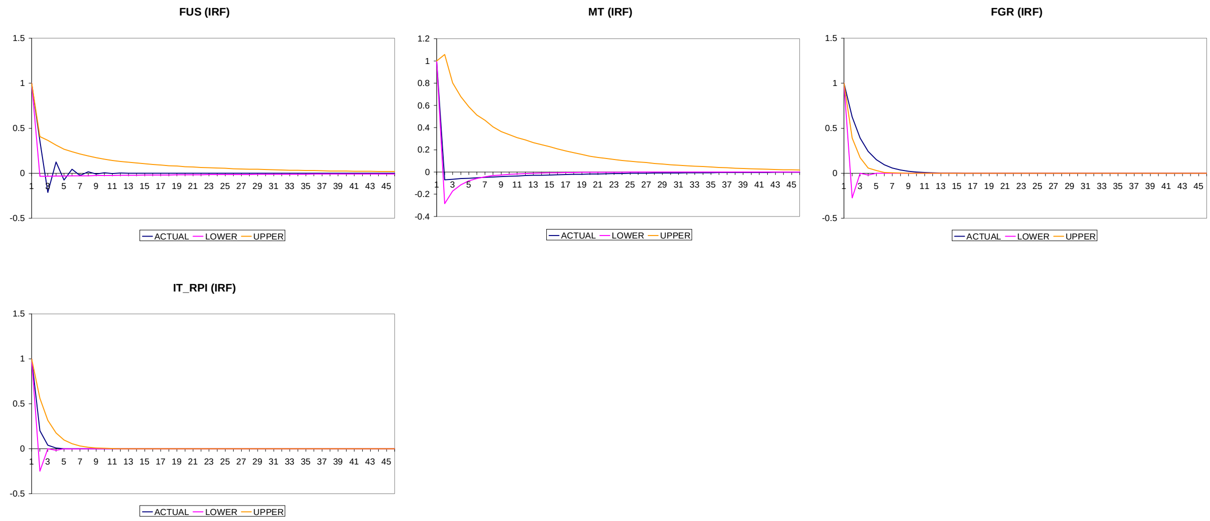

Figure 6: New Keynesian Impulse Response Functions with 95% Bounds (low stickiness)

We also look at several robustness tests (Annex C for full details). First, we examined the possibility that the monetary regime inflation behaviour was better captured by an AR(2) than the ARMA(1,1) we assumed; though the last fits better the other is close and yields a much higher estimate of persistence. Second, we looked at the case where the interest elasticity of the demand for money was much higher (ten times) than we assumed as is sometimes found. In both these cases the superiority of the New Classical model was enhanced.

Third we looked at the alternative break dates estimated with the Qu-Perron test. In this case we found a change in the ranking (see next table): the low stickiness version of the New Keynesian model did marginally better with these breaks than the New Classical. Both these models with slight inflation stickiness still dominate the other much more sticky New Keynesian models which are both rejected in three out of four regimes.

	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	−∞	−0.79	−19.10	0.33	−∞ (−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 13: Log-likelihood of Observing the Data-Generated ARMA Parameters Under Each Model and Regime

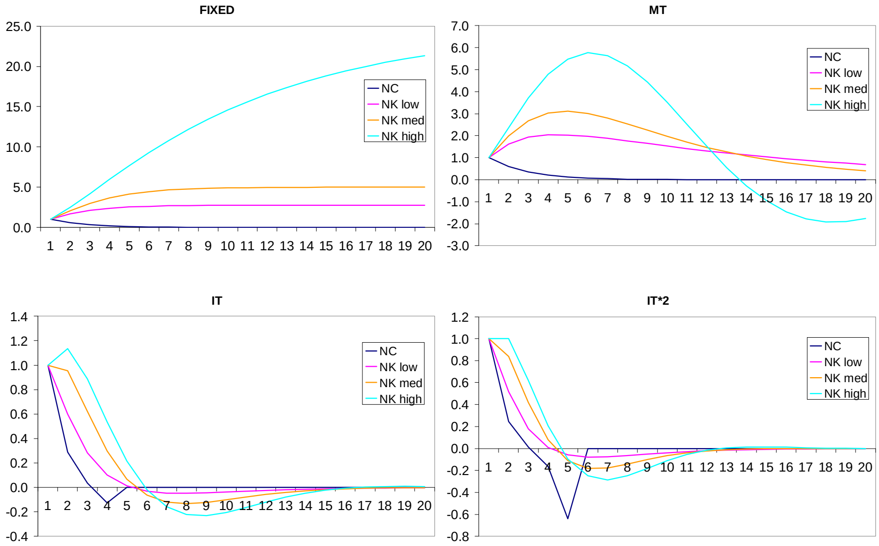

Figure 7: Inflation impulse response functions for a supply shock (AR=0.6) by model and regime-Fix=FUS,FGR; ITx2=IT but with coefficient on inflation doubled.

	Targeting Regimes				
	Bretton Woods	Monetary	Exchange Rate	Inflation	Total
New Keynesian					
High Stickiness	-27.76	-3.41	-28.28	−2.16	−61.62
Medium Stickiness	-5.65	-3.16	-9.86	−9.91	−28.58
Low Stickiness	-8.56	-7.12	-1.08	0.33	−16.43
New Classical	-0.35	-5.84	-14.64	0.45	−20.38

Table 14: Qu-Perron breaks: Log-likelihood of Observing the Data-Generated ARMA Parameters Under Each Model and Regime

Finally, we looked at an alternative time-series equation for inflation estimated by Boero et al. (2008). While the resulting estimates of persistence differed in detail from ours, it remained the case that the same two models with low stickiness dominated, again with our original breaks marginally favouring the New Classical and the Qu-Perron breaks marginally favouring the low-stickiness New Keynesian.

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 build a large degree of persistence into the Phillips Curve and this degree of persistence is not sufficiently sensitive to variations in the monetary regime 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 stickiness 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 stickiness. 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 monetary regimes change, especially the exogenously imposed degree of stickiness in the New Keynesian models (Gertler and Leahy, 2008, for example make pricing depend on the productivity state). 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 inflation stickiness.

References

[1] Akaike, H., (1973), 'Information Theory and An Extension of the Maximum Likelihood Principle', in B. Petrov and F. Csaki (eds.), Second International Symposium on Information Theory, Budapest: Akademia Kiado, 267–81.

[2] Andrews, D. and Chen, W., (1994), 'Approximately Median-Unbiased Estimation of Autoregressive Models', *Journal of Business and Economic Statistics*, Vol. 12, 187–204.

[3] Andrews, D., (1993a), 'Tests for Parameter Instability and Structural Change With Unknown Change Point', *Econometrica*, Vol. 4, 821–56.

[4] Andrews, M., Minford, P. and Riley, J., (1996), 'On Comparing Macroeconomic Models Using Forecast Encompassing Tests', *Oxford Bulletin of Economics and Statistic*s, Vol. 58, 2, 279–305.

[5] Armington, Paul S., (1969). 'A Theory of Demand for Products Distinguished by Place of. Production', IMF Staff Papers, 16(1), 159-176. ...

[6] Ball, L., (1999), 'Policy Rules for Open Economies', in J. Taylor (ed.), Monetary Policy Rules, Chicago: University of Chicago Press.

[7] Ball, L., (2000), 'Near-Rationality and Inflation in Two Monetary Regimes', NBER Working Paper No. 7988.

[8] Batini, N. and Haldane, A., (1999), 'Forward-Looking Rules for Monetary Policy', in J. Taylor (ed.), Monetary Policy Rules, Chicago: University of Chicago Press.

[9] Batini, N., (2006), 'Euro Area Inflation Persistence', Empirical Economics, 31, (4), 977-1002

[10] Benati, L. (2004), 'Evolving post-world war II UK economic performance', *Journal of Money Credit and Banking*, 36, 691–717.

[11] Boero, G., Smith, J. and Wallis, K. (2009) 'Modelling UK inflation uncertainty, 1958-2006'. In Volatility and Time Series Econometrics: Essays in Honour of Robert F. Engle (M. Watson, T. Bollerslev and J. Russell, eds). Oxford: Oxford University Press, forthcoming.

[12] Brainard, W. and Perry, G., (2000), 'Making Policy in a Changing World', G. Perry and J. Tobin (eds.), Economic Events, Ideas and Policies: The 1960s and After, Brookings Institution Press.

[13] Buiter, W. and Jewitt, I., (1981), 'Staggered Wage Setting with Real Wage Relativities: Variations on a Theme of Taylor', *The Manchester School*, Vol. 49, 211-228, reprinted in W. Buiter (ed.), Macroeconomic Theory and Stabilisation Policy, Manchester University Press, Manchester (1989).

[14] Calvo, G. (1983) 'Staggered prices in a utility-maximizing framework', *Journal of Monetary Economics*, 12,383–98.

[15] Calvo, G., Celasun, O. and Kumhof, M., (2001), 'A Theory of Rational Inflationary Inertia', University of Maryland, manuscript.

[16] Canova, F. (2005), *Methods for Applied Macroeconomic Research*, Princeton University Press, Princeton.

[17] Chow, G., (1960), 'Tests of Equality Between Sets of Coefficients in Two Linear Regressions', *Econometrica*, Vol. 28, 591–605.

[18] Christiano, L., Eichenbaum, M. and Evans, C., (2005), 'Nominal Rigidities and the Dynamic Effects of A Shock to Monetary Policy', *Journal of Political Economy,* 113, 1–45.

[19] Clarida, R., J. Gali, and M. Gertler (2000) 'Monetary policy rules and macroeconomic stability: evidence and some theory', *Quarterly Journal of Economics*, 140(1), 147-180.

[20] Cogley, T. and Sargent, T. (2002) 'Evolving post-World War II US inflation dynamics' in Gertler, M and Rogoff, K. (eds) NBER Macroeconomics Annual 2001, MIT Press, Cambridge.

[21] Dittmar, R., Gavin, W. and Kydland, F., (1999), 'The Inflation-Output Variability Tradeoff and Price Level Targets,' Federal Reserve Bank of St. Louis Review, Vol. 81, 1, 23–31.

[22] Dittmar, R., Gavin, W. and Kydland, F., (2001), 'Inflation Persistence and Flexible Prices', Federal Reserve Bank of St. Louis Working Paper No. 01/10.

[23] Friedman, M., (1980), 'Memorandum on Monetary Policy', House of Commons Treasury and Civil Service Committee, Memoranda on Monetary Policy, HMSO, Norwich, 55–68.

[24] Fuhrer, J. and Moore, G., (1995), 'Inflation Persistence', *Quarterly Journal of Economics*, Vol. 110, 127–60.

[25] Fuhrer, J., (2000), 'Habit Formation in Consumption and Its Implications for Monetary Policy Models', *American Economic Review*, Vol. 90, 367–90.

[26] Gertler, M. and J. Leahy (2008) 'A Phillips curve with an Ss foundation', *Journal of Political Economy*, 116(3), 533-572.

[27] Gregory, A. and Smith, G. (1991), 'Calibration as testing: Inference in simulated macro models', *Journal of Business and Economic Statistics* **9**, 293–303.

[28] Gregory, A. and Smith, G. (1993), Calibration in macroeconomics, *in* G. Maddala, ed., 'Handbook of Statistics'. vol. 11, Elsevier, St.Louis, Mo., 703-719.

[29] Gourieroux, C., Monfort, A. and Renault, E. (1993), 'Indirect inference', *Journal of Applied Econometrics* **8**, 85–118.

[30] Gourieroux, C. and Monfort, A. (1995), 'Simulation based econometric methods', CORE Lectures Series, Louvain-la-Neuve.

[31] Haldane, A., (2000), 'Ghostbusting: The UK Experience of Inflation Targeting', prepared for High Level Seminar: Implementing Inflation Targets, sponsored by IMF Institute.

[32] Ireland, P., (2000), 'Expectations, Credibility and Time-Consistent Monetary Policy', *Macroeconomic Dynamics*, Vol. 4, 448–66.

[33] Ireland, P., (2003a), 'A Method for Taking Models to Data', Boston College, mimeo.

[34] Ireland, P., (2003b), 'Endogenous money or sticky prices?' *Journal of Monetary Economics*, 50(8), 1623-1648.

[35] Kerr, W. and King, R., (1996), 'Limits on Interest Rate Rules in the IS-LM Model', Federal Reserve Bank of Richmond Economic Quarterly, Vol. 82, 47–75.

[36] Kim, C., Nelson, C. and Piger, J., (2001), 'The Less Volatile US Economy: A Bayesian Investigation of Timing, Breadth, and Potential Explanations', Board of Governors of the Federal Reserve System, International Finance Discussion Papers No. 707.

[37] Le, V.P.M. and Minford, P., (2007), 'Calvo Contracts: Optimal Indexation and General Equilibrium', Cardiff Economics Working Paper E2007/8.

[38] Levin, A., Natalucci, F. and Piger, J., (2004), 'The Macroeconomic Effects of Inflation Targeting', Federal Reserve Bank of St. Louis Review, Vol. 86, 4, 51–80.

[39] Lucas, R.E. (1976) 'Econometric policy evaluation: a critique', in K. Brunner and A.H. Meltzer (eds.) *The Phillips Curve and Labour Markets*, Carnegie Rochester Conference Series on Public Policy No.1, Supp. to Journal of Monetary Economics.

[40] Mankiw, N. and Reis, R., (2002) 'Sticky Information Versus Sticky Prices: A Proposal to Replace the New Keynesian Phillips Curve', *Quarterly Journal of Economics*, Vol 117(4), 1295–1328

[41] Marques, C., (2004), 'Inflation Persistence: Facts or Artefacts?', ECB Working Paper No. 371.

[42] McCallum, B. and Nelson, E., (1997), 'An Optimizing IS-LM Specification for Monetary Policy and Business Cycle Analysis', NBER, Working Paper No. 5875.

[43] McCallum, B. and Nelson, E., (1999a), 'Nominal Income Targeting in an Open-Economy Optimizing Model', *Journal of Monetary Economics*, Vol. 43, 553–78.

[44] McCallum, B. and Nelson, E., (1999b), 'Performance of Operational Policy Rules in an Estimated Semiclassical Structural Model', Monetary Policy Rules, (ed.) J. Taylor, Chicago: University of Chicago Press.

[45] McCallum, B., (2001), 'Should Monetary Policy Respond Strongly to Output Gaps?,' *American Economic Review* Papers and Proceedings 91, May, 258–62.

[46] Meenagh, D., Minford, P. and Wickens, M. (2008) 'Testing a DSGE model of the EU using indirect inference', mimeo, Cardiff University.

[47] Minford, P., (1993), 'Monetary Policy in the other G7 Countries: the United Kingdom', in M. Fratianni and D. Salvatore (eds.), Monetary Policy in Developed Economies, Handbook of Comparative Economic Policies, Vol. 3, Westport, Conn. And London: Greenwood Press, 405–31.

[48] Minford, P., and Peel, D (2002) 'Advanced Macroeconomics — A Primer', Edward Elgar Publishing Ltd.

[49] Nelson, E., (2000), 'UK Monetary Policy 1972–97: A Guide Using Taylor Rules', Bank of England Working Paper No. 120.

[50] Nelson, E., (2001), 'What Does the UK's Monetary Policy and Inflation Experience Tell Us About the Transmission Mechanism?', CEPR Discussion Paper No. 3047.

[51] Nelson (2007) 'An overhaul of doctrine: the underpinning of UK inflation targeting'. working paper 2007-026B, Federal Reserve bank of St. Louis.

[52] Nelson and Nikolov (2004) 'Monetary policy and stagflation in the UK', *Journal of Money Credit and Banking*, 36, 293–318.

[53] Orphanides, A., (1998), 'Monetary Policy Evaluation with Noisy Information,' Finance and Economics Discussion Series 1998-50, Board of Governors of the Federal Reserve System, US.

[54] Perron, P., (1990), 'Testing for A Unit Root in a Time Series with a Changing Mean', *Journal of Business and Economic Statistics*, Vol. 8, 153–62.

[55] Phillips, P, (1991), 'To Criticize the Critics: An Objective Bayesian Analysis of Stochastic Trends', *Journal of Applied Econometrics*, Vol. 6, 333–64.

[56] Pivetta, F. and Reis, R., (2007), 'The Persistence of Inflation in the United States', *Journal of Economic Dynamics and Control*, 31, 1326–1358.

[57] Popper, K. (1934) *The Logic of Scientific Discovery*, reprinted Routledge Classics, London.

[58] Qu, Z. and Perron, P. (2007) 'Estimating and Testing Structural Changes in Multivariate Regressions', *Econometrica* 75 (2), 459–502.

[59] Ravenna, F., (2000), 'The Impact of Inflation Targeting in Canada: A Structural Analysis', New York University, mimeo.

[60] Roberts, J., (1998), 'Inflation Expectations and the Transmission of Monetary Policy', Board of Governors of the Federal Reserve System.

[61] Rotemberg, J. and Woodford, M., (1997), 'An Optimizing-Based Econometric Framework for the Evaluation of Monetary Policy', in B. Bernanke and J. Rotemberg (eds.), NBER Macro Economics Annual 1997, Cambridge, The MIT Press.

[62] Rudd, J. and Whelan, K. (2005) 'New tests of the new-Keynesian Phillips curve', *Journal of Monetary Economics*, 52(6), September, 1167–1181.

[63] Rudebusch, G. and Svensson, L., (1999), 'Policy Rules for Inflation Targeting', in J. Taylor (ed.), Monetary Policy Rules, Chicago: University of Chicago Press.

[64] Schwartz, G., (1978), 'Estimating the Dimension of a Model', *Annals of Statistics*, Vol. 6, 461–64.

[65] Shoemaker, O. (2006) 'Variance estimates for changes in the consumer price index, January 2006–December 2006', http://www.bls.gov/cpi/cpivar2006.pdf.

[66] Sims, C., (2001), 'Implications of Rational Inattention', Princeton University, manuscript.

[67] Smets, F. and Wouters, R. (2003) 'An estimated stochastic DGSGE model of the euro area', *Journal of the European Economic Association*, 1, 1123–1175.

[68] Smith, A. , 1993. 'Estimating nonlinear time-series models using simulated vector autoregressions', *Journal of Applied Econometrics*, 8, S63-S84.

[69] Taylor, J., (2000), 'Low Inflation, Pass-Through and the Pricing Power of Firms', *European Economic Review*, Vol. 44, 1389–408.

[70] West, K.D. (1988) 'On the interpretation of near random-walk behaviour in GNP', *American Economic Review*, 78(1), 202–209.

[71] Woodford, M., (2001), 'Imperfect Common Knowledge and the Effects of Monetary Policy', NBER Working Paper No. 8673.

Annex A A final robustness test

In the period since we wrote this paper we developed improvements in our methods for testing under Indirect Inference. Thus we wished to establish whether our results would be robust to implementing these, as well as some other more minor changes in method.

The changes concerned were as follows:

1) in estimating the structural errors in each model we used the model to generate the expectations wherever these entered. This method is an iterative one since the expectations depend importantly on the autoregressive coefficients of the errors, while these coefficients in turn depend on the errors that are generated. We decided that a superior method was to use the robust estimation procedure suggested by McCallum (1976) and Wickens (1982) in which the expectations are generated by instrumental variable regressions; as instruments we used the lagged values of the data, so that we used a VAR(1) of output, inflation and interest rates to generate the estimated expectations used in estimating the structural errors.

2) in bootstrapping the shocks we chose a random set of shocks for the current and next five quarters for each period; for the following period, the resulting lagged values from this simulation were used in conjunction with another drawing of six current and future shocks; and so on until the whole bootstrap of overlapping shocks was completed. Thus agents are obtaining in each period new information about the shocks, not merely for the current quarter but also for succeeding quarters. This is how many forecasts are constructed, with an interpretation each quarter of the whole pattern of current and future shocks. A simpler alternative which we now normally use is to shock only the current quarter.

3) we check explicitly for any roots on or outside the unit circle in the AR or MA coefficients of the bootstrap regressions; any bootstrap regressions where the roots are not inside the unit circle are discarded from the bootstrap distribution as providing no information[1].

When we implement these changes we find that out of the New Classical and the low-persistence New Keynesian that were the dominant models in our previous results, only the New Classical survives as a credible explanation of inflation persistence, even though it still fails to replicate the behaviour of the Exchange Rate targeting regime. The New Keynesian models generate excessive persistence in all regimes whatever their degree of stickiness. The Impulse Response Functions and their 95% bounds are shown below for all models/ regimes; they show clearly how the NK regimes all overpredict persistence. Thus our conclusion remains that inflation persistence depends essentially on the monetary regime and the persistence of exogenous shocks, rather than on some inherent persistence produced by stickiness in the Phillips Curve.

[1] We ended up with the following number of bootstraps for each regime:

	NC	NK High	NK Medium	NK Low
FUS	727	885	595	469
MT	1000	969	918	800
FGR	1000	511	766	641
SIT	929	983	941	717

The alternative to excluding the ARMAs from these bootstraps would have been to use constrained Maximum Likelihood estimation throughout, constraining the roots to be inside the unit circle. However that lay beyond our scope here.

A.1 Results for the New Classical models:

		Estimated	95% Confidence Interval		Wald
			Lower	Upper	statistic
Bretton Woods	AR(1)	−0.582286	−0.928188	0.999054	99.0
(FUS)	MA(1)	0.953580	−0.997443	0.978302	
Incomes Policy	AR(1)	0.735372	0.427389	0.854566	42.0
(IP)					
Money Targeting	AR(1)	0.343938	0.068618	0.710834	75.3
(MT)	AR(2)	0.375406	−0.267597	0.471731	
Exchange Rate Targeting	AR(1)	0.641620	0.340258	0.434509	100.0
(FGR)					
Inflation Targeting (RPI)	AR(1)	−0.669711	−0.334630	1.255148	94.0
(IT)	AR(2)	0.312549	−0.622034	0.473081	
	MA(1)	0.985220	−0.979062	0.997391	

Table 1: Confidence Limits the New Classical Model for Theoretical ARMAs

A.2 Results for the New Keynesian models:

A.2.1 High stickiness (low-ν:)

		Estimated	95% Confidence Interval		Wald
			Lower	Upper	statistic
Bretton Woods	AR(1)	−0.582286	0.959540	0.998876	100.0
(FUS)	MA(1)	0.953580	−0.064583	0.669371	
Money Targeting	AR(1)	0.343938	1.410441	1.860496	100.0
(MT)	AR(2)	0.375406	−0.957609	−0.425155	
Exchange Rate Targeting	AR(1)	0.641620	0.972970	0.999088	100.0
(FGR)					
Inflation Targeting (RPI)	AR(1)	−0.669711	−0.070916	1.560340	100.0
(IT)	AR(2)	0.312549	−0.694673	0.847232	
	MA(1)	0.985220	−0.569893	0.966081	

Table 2: Confidence Limits from the New Keynesian Model for Theoretical ARMAs

A.2.2 Medium stickiness (ν: is 0.5)

		Estimated	95% Confidence Interval		Wald
			Lower	Upper	statistic
Bretton Woods	AR(1)	−0.582286	0.992301	1.003105	100.0
(FUS)	MA(1)	0.953580	−1.318379	0.086075	
Money Targeting	AR(1)	0.343938	1.005464	1.656545	100.0
(MT)	AR(2)	0.375406	−0.692355	−0.018083	
Exchange Rate Targeting	AR(1)	0.641620	0.974883	1.047992	100.0
(FGR)					
Inflation Targeting (RPI)	AR(1)	−0.669711	−0.124747	1.459610	100.0
(IT)	AR(2)	0.312549	−0.656741	0.841686	
	MA(1)	0.985220	−0.945823	0.974431	

Table 3: Confidence Limits from the New Keynesian Model for Theoretical ARMAs

A.2.3 Low stickiness (ν:=0.9)

		Estimated	95% Confidence Interval Lower	Upper	Wald statistic
Bretton Woods (FUS)	AR(1)	−0.582286	0.998736	0.999978	100.0
	MA(1)	0.953580	−0.997468	−0.938055	
Money Targeting (MT)	AR(1)	0.343938	0.590426	1.296314	100.0
	AR(2)	0.375406	−0.308719	0.404206	
Exchange Rate Targeting (FGR)	AR(1)	0.641620	0.985248	0.999757	100.0
Inflation Targeting (RPI) (IT)	AR(1)	−0.669711	−0.169801	1.301428	100.0
	AR(2)	0.312549	−0.407000	0.807397	
	MA(1)	0.985220	−0.948954	0.997264	

Table 4: Confidence Limits from the New Keynesian Model for Theoretical ARMAs

A.3 Comparing the models

	Targeting Regimes				
	Bretton Woods	Monetary	Exchange Rate	Inflation	Total
New Keynesian					
High Stickiness	$-\infty$	−245.47	$-\infty$	−381.57	$-\infty$
Medium Stickiness	$-\infty$	−283.44	$-\infty$	−96.41	$-\infty$
Low Stickiness	$-\infty$	−204.85	$-\infty$	−37.88	$-\infty$
New Classical	−6.75	0.55	−56.78	−3.34	−66.32

Table 5: Log-likelihood of Observing the Data-Generated ARMA Parameters Under Each Model and Regime

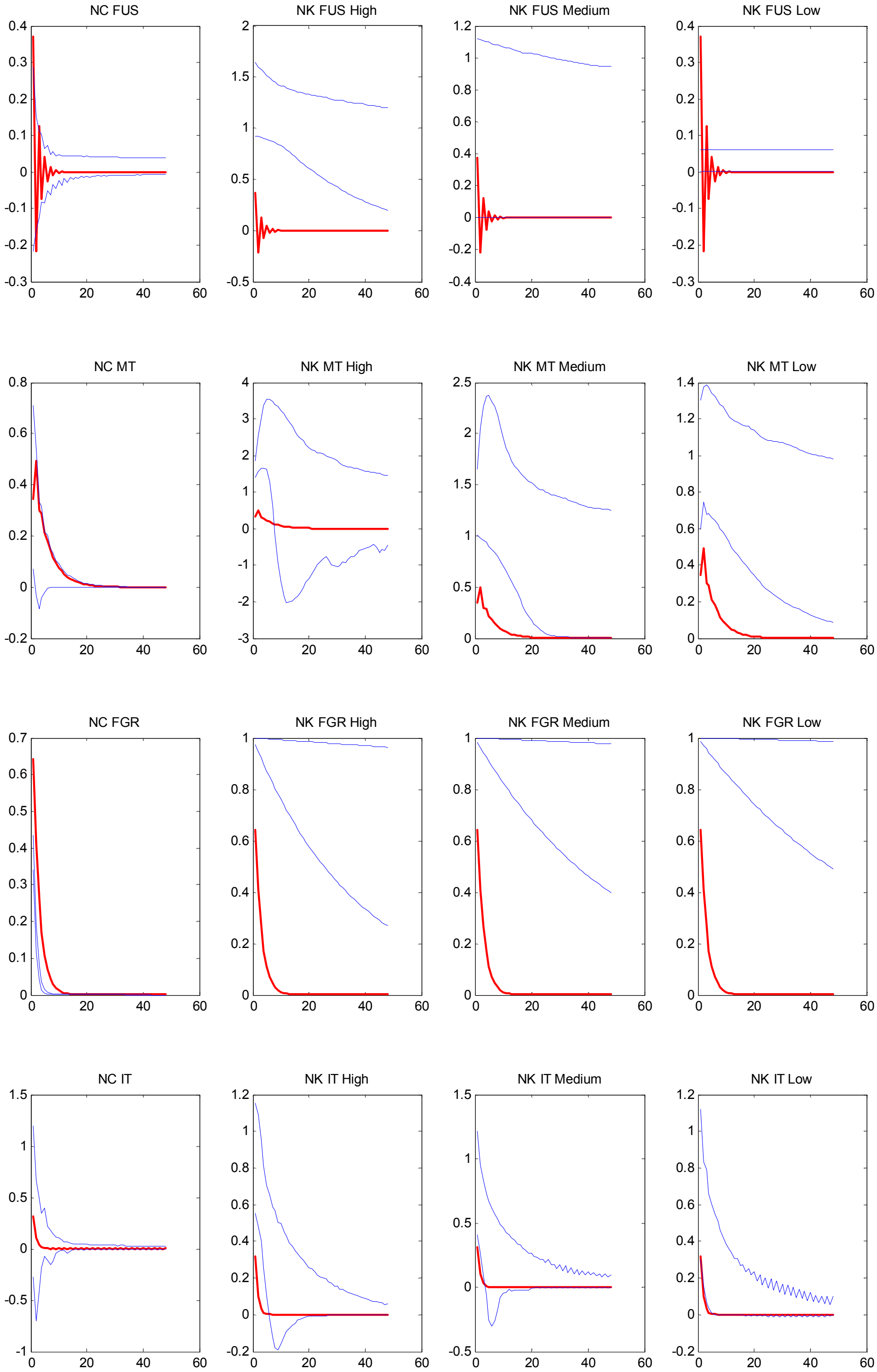

Figure 1: IRFs of ARMAs with 95% bounds