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RESEARCH DISCUSSION PAPER

Inflation Volatility and Forecast Accuracy

Jamie Hall and
Jarkko Jääskelä

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Authors: hallcj or jaaskelaj at domain rba.gov.au

Economic Publications: ecpubs@rba.gov.au

Abstract

This paper examines the statistical properties of inflation in a sample of inflation-targeting and non-inflation-targeting countries. First, it analyses the time-varying volatility of a measure of the persistent component of inflation. Based on this measure, inflation-targeting countries (Australia, Canada, New Zealand, Sweden and the United Kingdom) have experienced a relatively more pronounced fall in the volatility of inflation than non-inflation-targeting countries (Austria, France, Germany, Japan and the United States). But it is hard to say whether inflation is more volatile in inflation-targeting or non-inflation-targeting countries. Second, it analyses whether inflation became easier to forecast after the introduction of inflation targeting. It finds that inflation became easier to forecast in both inflation-targeting and non-inflation-targeting countries; the improvement was greater for the former group but forecast errors remain smaller for the latter group.

JEL Classification Numbers: C53, E37
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1. Introduction

Over the twenty years to 2008, the level and volatility of inflation has declined across the world (Table 1). Average CPI inflation across the major countries fell from 6.0 per cent over 1977–1992 to 2.0 per cent over 1993–2008, while the unconditional standard deviation fell from 3.7 per cent to 1.6 per cent over the same period. While these trends are common to all countries, the extent of change has varied across countries consistent with the tendency for convergence of both the level and volatility of inflation.[1]

There is a literature examining the role of monetary regimes in explaining these changes, with one particular focus on differences between inflation-targeting (IT) and non-IT regimes (see, for example, Bernanke *et al* 2001). Others, such as Geraats (2002), Chortareas, Stasavage and Sterne (2001) and Demertzis and Hughes Hallett (2007), study how the precise nature of the policy framework, such as the degree of central bank transparency, is related to the volatility and level of inflation. Many of these studies rely on simple measures of inflation behaviour, such as unconditional means and variances, and are usually based on headline measures of inflation. However, such measures can be overly influenced by very temporary movements in inflation. This means that the sample period for the analysis can have an important influence on the results. More importantly, these temporary effects may have little if anything to do with differences in policy frameworks and much more to do with different structural features of the economy, such as its size or openness to trade. One alternative is to focus on underlying or core measures of inflation. However, there is no widespread agreement on the best way to do this, and comparable measures across a wide range of countries are not

1 The decline in inflation volatility has not come about because central banks were willing to tolerate higher output volatility. In fact, at least over the period up to 2008, output volatility has tended to decline (see Table F1; Stock and Watson 2005 and Kent, Smith and Holloway 2005). It may be that economies have faced a more benign inflation-output volatility trade-off over this period and/or that policy has played some role – see Cecchetti, Flores-Lagunes and Krause (2006), for example.

Table 1: Level and Volatility of Inflation

	1977–2008	1977–1992	1993–2008
		Inflation[(a)]	
Australia	5.00	7.28	2.66
Austria	2.89	3.74	2.02
Canada	4.09	6.18	1.93
France	4.18	6.59	1.70
Germany	2.50	3.18	1.80
Japan	1.57	2.95	0.14
NZ	5.79	9.20	2.26
Sweden	4.70	7.69	1.61
UK	5.23	7.59	2.79
US	4.19	5.64	2.70
Average	4.01	6.00	1.96
		Inflation volatility[(b)]	
Australia	3.46	3.33	1.44
Austria	2.04	2.16	1.48
Canada	3.53	3.40	2.08
France	3.95	4.20	1.20
Germany	2.01	2.23	1.47
Japan	2.67	2.85	1.48
NZ	5.41	5.59	1.67
Sweden	4.63	4.35	2.32
UK	4.47	5.12	1.39
US	3.01	3.47	1.29
Average	3.52	3.67	1.58

Notes: (a) Inflation is measured as the average quarterly change in seasonally adjusted headline CPI expressed on an annualised basis.
(b) Volatility is measured by the standard deviation of annualised quarterly inflation.

readily available. Another alternative is to use a statistical model to try to separate headline inflation into persistent and temporary components.

This paper adopts this latter approach, examining the inflation process in five IT countries (Australia, Canada, New Zealand, Sweden and the United Kingdom) and five non-IT countries (Austria, France, Germany, Japan and the United States) using a statistical model introduced by Stock and Watson (2007). The Stock and Watson approach decomposes inflation into permanent and transitory components, the variabilities of which are allowed to change over time. Using measures based on this unobserved components stochastic volatility (UC-SV) model, we find little support for sharp distinctions between countries in terms of the level and volatility of the permanent component of inflation.[2]

A related approach is to examine the forecastability of inflation.[3] An effective and credible monetary policy regime, other things equal, will help to keep inflation anchored closely around a low and constant mean. By itself, this implies that inflation should be easier to forecast – that is, forecast errors will tend to be small.

To examine the forecastability of inflation, we used a modified version of the Stock and Watson model (M-UC-SV). Following a suggestion of Pagan (2008), we model the time-varying volatilities as autoregressive processes of order one (AR(1)), so that they have finite second moments. And instead of assuming that the permanent level of inflation follows a random walk, we use a mean-reverting AR(1), with a freely estimated degree of persistence. These assumptions imply that inflation is a stationary process that can be decomposed into temporary and persistent (but not permanent) components, consistent with the notion that monetary policy can influence inflation and provide a nominal anchor.

In brief, we find that inflation forecastability improved over time across our sample of selected IT and non-IT countries, both in absolute terms and relative to naïve forecasts. Across countries, the out-of-sample forecast error of the M-UC-SV model tends to be somewhat smaller than that of the original UC-SV model. Furthermore, it seems that the improvement in inflation forecastability was more pronounced in IT countries than in non-IT countries.

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2 Related work has documented the quantitative effects of inflation targeting. Kuttner and Posen (2001) document that inflation targeting reduces the persistence of inflation. Benati (2008) concludes that inflation is highly persistent in policy regimes that lack a well-defined nominal anchor. Pivetta and Reis (2007) find that inflation persistence has been high and approximately unchanged in the United States since 1965. Cogley, Primiceri and Sargent (2008) argue that this finding can be viewed simply as a manifestation of shifts in average (or the target for) inflation. They conclude that inflation persistence has decreased since the 1980s.

3 Earlier literature has looked at survey-based inflation expectations. Levin, Natalucci and Piger (2004) find that inflation targeting is effective in anchoring inflation expectations. Johnson (2002) finds that the level of expected inflation in targeting countries falls after the announcement of targets. However, neither the variability of surveyed inflation expectations nor the average absolute survey-based forecast error fall after the announcement of targets.

The rest of the paper is organised as follows. Section 2 describes the UC-SV model and its modified version M-UC-SV together with a description of the data used in the analysis. Section 3 presents the within-sample results on the inflation process based on the UC-SV model. Section 4 presents results on the forecastability of inflation where the focus is on the M-UC-SV model. Section 5 concludes.

2. Methodology and Data

Our benchmark model follows Stock and Watson (2007), who characterise the inflation process with an unobserved component model with stochastic volatility (UC-SV). In this model, inflation (π_t) is expressed as the sum of a permanent stochastic component (τ_t) and a transitory innovation component (η_t) as per Equation (1). The permanent component of inflation evolves as a random walk without drift as in Equation (2).[4] The variance of the shocks (ε_t) to this component can change over time, as can the variance of the transitory innovations.

$$\pi_t = \tau_t + \eta_t \tag{1}$$
$$\tau_t = \tau_{t-1} + \varepsilon_t \tag{2}$$

$$\varepsilon_t \sim N(0, \sigma_{\varepsilon,t}) \qquad \eta_t \sim N(0, \sigma_{\eta,t})$$

$$\log(\sigma^2_{\varepsilon,t}) = \log(\sigma^2_{\varepsilon,t-1}) + \nu_{\varepsilon,t} \tag{3}$$
$$\log(\sigma^2_{\eta,t}) = \log(\sigma^2_{\eta,t-1}) + \nu_{\eta,t} \tag{4}$$

$$\nu_{\varepsilon,t} \sim N(0, \gamma_\varepsilon) \qquad \nu_{\eta,t} \sim N(0, \gamma_\eta)$$

The relative importance of τ and η is determined by their variances (σ^2_ε and σ^2_η), which evolve as independent random walks (without drift). The only parameters of the model are γ_ε and γ_η, which are the standard deviations of ν_ε and ν_η. They control the speed at which the size of the permanent and transitory shocks can

4 See also Cogley and Sargent (2001, 2005), Ireland (2007), and Cogley and Sbordone (2008) for papers that model trend inflation in this way.

change. If all the $v_{i,t}$ shocks were zero after date t_0, then the variances σ_ε^2 and σ_η^2 would stay fixed at their date t_0 values, and the model would simply become a random walk observed with noise, as in Equations (1) and (2).

Using Equations (1) to (4), we can estimate the evolution of τ_t, $\sigma_{\varepsilon,t}^2$ and $\sigma_{\eta,t}^2$, conditional on inflation data (π_t).[5] It is possible to set the values of γ_ε and γ_η by calibration – Stock and Watson (2007, 2008) use this approach – but we chose to estimate them, and thereby allow for cross-country variation in our analysis.

2.1 A Modification of the Stock and Watson Model

This section describes a modified version of the UC-SV model (M-UC-SV), which in principle should be preferred when looking at questions related to forecasts. While the model of Stock and Watson (2007, 2008) provides a useful way to assess the within-sample properties of the inflation process, it is less satisfactory for questions related to forecastability. In particular, their model implies that inflation has a unit root and the variances of the permanent and the transitory components are unbounded, so the model becomes explosive over longer horizons (Pagan 2008; Bos, Koopman and Ooms 2007).[6]

The M-UC-SV model relaxes the assumption that the permanent component of inflation is a random walk, and assumes instead that there are persistent shocks around a fixed mean (μ):

$$\pi_t = \mu + \tau_t + \eta_t \tag{5}$$

$$\tau_t = \phi \tau_{t-1} + \varepsilon_t \tag{6}$$

where ϕ is constrained to be less than one in absolute value. This constraint rules out an explosive root in inflation.

We also allow univariate stochastic volatility processes to evolve as auto-regressive processes:

$$\log(\sigma_{\eta,t}^2) = \rho \log(\sigma_{\eta,t-1}^2) + v_{\eta,t} \tag{7}$$

5 To do this we apply the Gibbs sampler.

6 If the model is used to simulate 50 years' worth of data, starting from initial values calibrated for the United States, at least one hyperinflation is very likely.

$$\log(\sigma^2_{\varepsilon,t}) = \rho \log(\sigma^2_{\varepsilon,t-1}) + \nu_{\varepsilon,t} \tag{8}$$

This assumption forces the variances of the persistent (ε_t) and temporary (η_t) components of inflation to be bounded; we estimate μ and ϕ using the Gibbs sampler, but calibrate ρ to 0.98.[7] In this model, if the $\nu_{i,t}$ shocks were set to zero after period t_0, then the logs of σ^2_ε and σ^2_η would converge to zero, meaning that their levels would approach one, so that the ε and η shocks in Equations (7) and (8) would become standard normals.

Our focus will be on the time-varying volatilities σ^2_η and σ^2_ε. For completeness, Tables C1, C2 and C3 in Appendix C provide estimates of μ, ϕ, γ_ε and γ_η for the countries in our sample.

2.2 Data

We use CPI series that are corrected (where possible) for changes to indirect taxation (and the direct effects associated with changes in interest rates).[8] In some cases it is not possible to correct inflation for the effects of movements in indirect taxes. We provide more details in Appendix A. For the United Kingdom we used the retail price index excluding mortgage interest (RPIX).

Where possible, we use data commencing in 1960. As described in Appendix A, we used seasonally adjusted quarterly data. Some countries publish seasonally adjusted CPI series; for the remainder, we used X-12-ARIMA to remove the seasonal component.[9]

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[7] We tried including a freely-estimated mean and AR(1) coefficient in Equations (7) and (8), but the Gibbs sampler became numerically unstable. Models with calibrated values of ρ between 0.9 and 0.99 are hard to distinguish; lower calibrated values produce slightly worse forecasting performance, and are not as stable numerically.

[8] We also performed the analysis using central bank 'preferred' measures of inflation (where applicable), such as the personal consumption expenditure deflator for the United States. In general, the results are broadly similar to those presented below.

[9] Monthly data were seasonally adjusted if needed and then converted to quarterly data by taking averages of the monthly observations.

3. Properties of Inflation

3.1 Level of Permanent Components

Figure 1 plots median estimates of the permanent component of inflation (τ) derived from the UC-SV model with actual inflation. All our models are estimated on quarterly inflation, but the results are presented on an annualised basis hereafter. Note that the graphs for the UK and the US have a different vertical scale than for other countries. Uncertainty is captured by 90 per cent confidence intervals around the permanent component shown in Figure D1. Unsurprisingly, the width of the confidence intervals is higher when inflation is more volatile.

Three features of Figure 1 are especially salient. First, although the peaks of the 'Great Inflation' period (1971–1983) can be seen in most countries, their relative size varies greatly, and the effects of country-specific shocks are readily apparent. Second, in the 1970s the estimated permanent component was high and volatile, tracking inflation itself. However, after 1990 the permanent component declined markedly, to a level that is relatively stable by historical standards. Finally, most countries experienced an increase in inflation in the last two years of the sample, much of which was due to a rise in the permanent component.[10]

More than the usual level of caution seems warranted when placing economic interpretations on the results of this statistical model. As already noted, the UC-SV model, taken literally, implies somewhat extreme behaviour of inflation (out-of-sample) – namely, that it has a unit root and that the variance of the change in inflation is infinite (Pagan 2008). With these caveats in mind, one interpretation is that the shocks to inflation in the 1970s were permanent (or at least very persistent), while the dominance of temporary shocks in the latter half of the sample shows that the permanent component of inflation became better anchored (Mishkin 2007).

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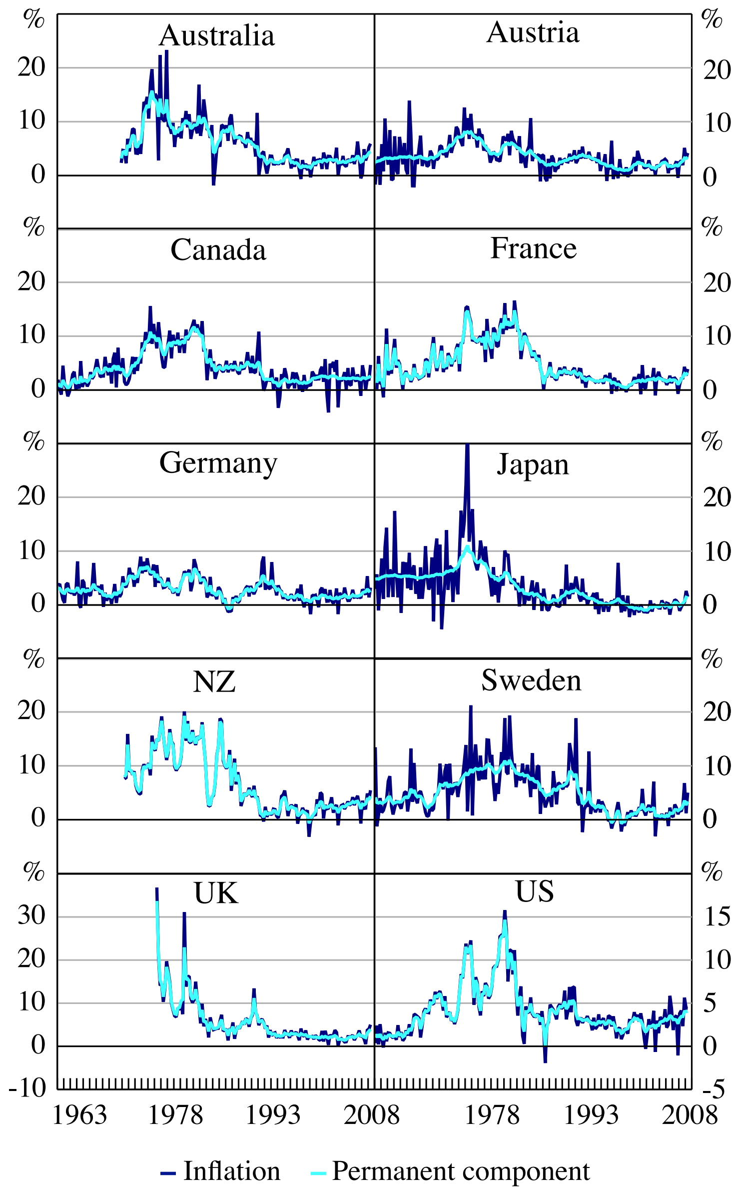
[10] Ireland (2007) and Cogley and Sbordone (2008) analyse US inflation dynamics using comparable techniques, and produce similar results. International comparisons are, however, scarce.

Figure 1: Inflation and its Permanent Component



Bernanke (2007) interprets Stock and Watson's results as evidence that inflation expectations in the United States were better anchored after 1990 than from 1970 to 1980, due to improvements in monetary policy. The results shown in Figure 1 are consistent with the same conclusion for all the countries in our sample; although there may be other plausible explanations (including the absence of large inflation shocks).

Table 2 reports simple summary statistics for the permanent component of inflation, τ. The first row for each country shows the sample average, $\overline{\tau}$. The

Table 2: Level and Volatility of the Permanent Component of Inflation

		1960–2008 (I)	1977–1992 (II)	1993–2008 (III)	Change (III)-(II)
Australia	$\overline{\tau}$	5.88	7.68	2.66	–5.02
	σ_τ	3.77	2.32	0.89	
	σ_τ/σ_π	0.85	0.75	0.62	
Austria	$\overline{\tau}$	3.50	3.79	2.11	–1.68
	σ_τ	1.84	1.42	0.91	
	σ_τ/σ_π	0.66	0.64	0.60	
Canada	$\overline{\tau}$	4.14	6.38	1.98	–4.40
	σ_τ	3.02	2.86	0.88	
	σ_τ/σ_π	0.86	0.87	0.44	
France	$\overline{\tau}$	4.73	6.91	1.71	–5.20
	σ_τ	3.75	3.94	0.72	
	σ_τ/σ_π	0.95	0.96	0.61	
Germany	$\overline{\tau}$	2.88	3.07	1.89	–1.18
	σ_τ	1.80	1.93	1.07	
	σ_τ/σ_π	0.82	0.84	0.72	
Japan	$\overline{\tau}$	3.20	2.97	0.21	–2.76
	σ_τ	3.18	2.08	0.89	
	σ_τ/σ_π	0.63	0.72	0.56	
NZ	$\overline{\tau}$	6.69	9.74	2.20	–7.54
	σ_τ	5.39	5.22	1.24	
	σ_τ/σ_π	0.98	0.97	0.75	
Sweden	$\overline{\tau}$	4.84	7.74	1.61	–6.13
	σ_τ	3.33	2.40	1.50	
	σ_τ/σ_π	0.74	0.58	0.65	
UK	$\overline{\tau}$	5.60	7.55	2.46	–5.09
	σ_τ	5.17	4.30	0.74	
	σ_τ/σ_π	0.94	0.88	0.73	
US	$\overline{\tau}$	4.14	5.79	2.73	–3.06
	σ_τ	2.83	3.30	0.78	
	σ_τ/σ_π	0.95	0.94	0.62	

second row gives the sample standard deviation of τ. The third row shows the ratio of that standard deviation to the standard deviation of inflation. The results show that the average of the permanent component after 1992 fell in all countries. It also appears that in the latter part of the sample, the permanent component of inflation converged somewhat across countries. Furthermore, the sample standard deviation of τ clearly fell in all countries between the first and second parts of the sample. Over time, the volatility of the permanent component tended to fall somewhat relative to the volatility of overall inflation for most, though not all, countries.

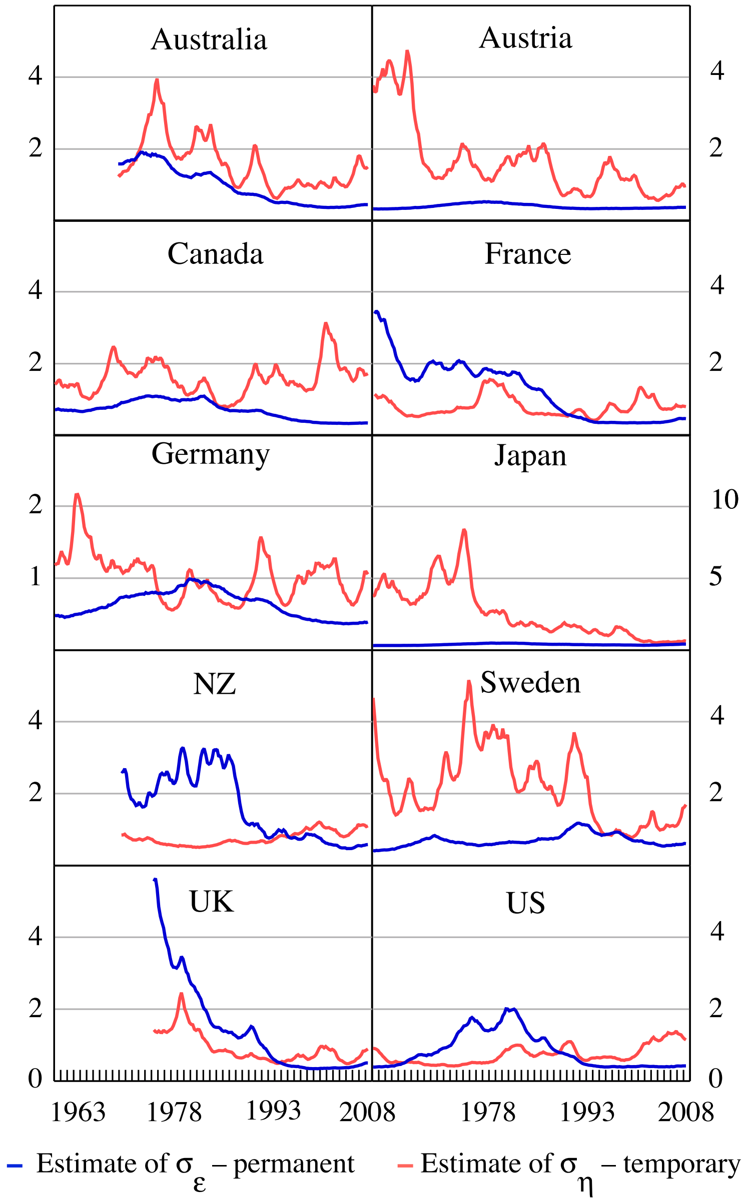
3.2 Time-varying Inflation Volatility

We turn now to the estimated time series of the volatilities of the permanent and transitory shocks to inflation, that is, $\sigma^2_{\varepsilon,t}$ and $\sigma^2_{\eta,t}$. (Note that these volatilities should not be confused with γ^2_{ε} and γ^2_{η}, which govern the magnitude of the time-variation in $\sigma^2_{\varepsilon,t}$ and $\sigma^2_{\eta,t}$.)

The time profiles of $\sigma_{\varepsilon,t}$ and $\sigma_{\eta,t}$ are shown in Figure 2. Figure 3 shows the ratio of the standard deviation of the permanent shocks to the sum of the standard deviations of the temporary and permanent shocks, that is, $\frac{\sigma_{\varepsilon,t}}{\sigma_{\eta,t}+\sigma_{\varepsilon,t}}$ (with 90 per cent confidence intervals).

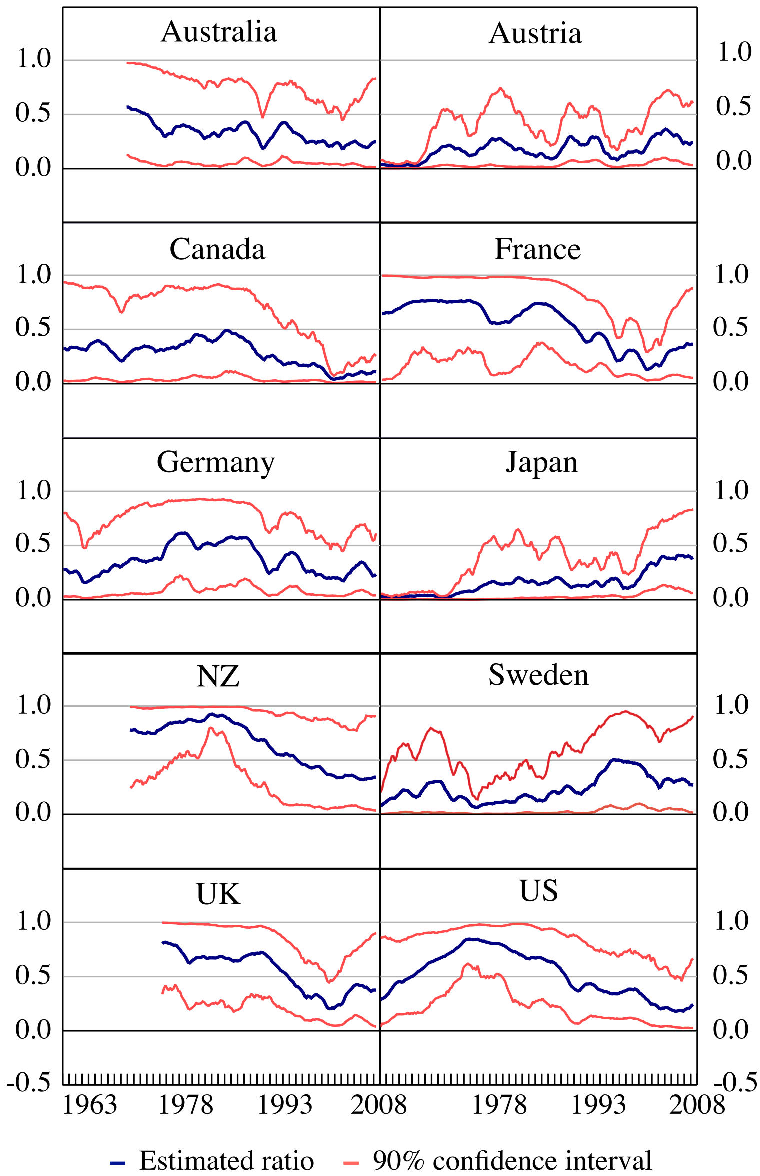
Across most countries in the sample, the high-inflation episodes of the 1970s were characterised by a relatively high level of variance of the permanent shocks, which had fallen by the mid 1990s. One interpretation is that the decline in the volatility of the permanent shocks (Figure 2) is evidence of a decrease in inflation uncertainty. Interestingly, the rise in the level of the permanent component of inflation in the 1970s (Figure 1) was matched by an increase in the volatility of the permanent shocks (Figure 2). The most recent estimates of the volatility of the permanent shocks are still very close to the sample lows in each country.

Figure 2: Median Estimates of the Standard Deviations of the Permanent (σ_ε) and Temporary (σ_η) Components of Inflation



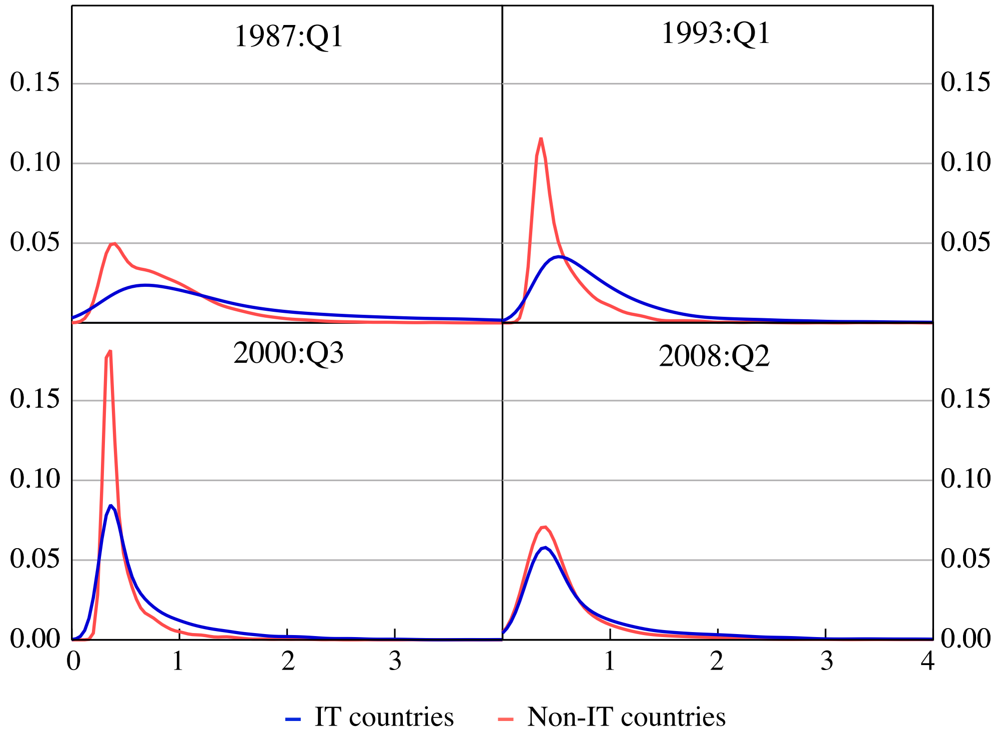
Focusing on the United States first, Figures 2 and 3 suggest that its monetary policy was less successful in stabilising inflation during the 1970s than at other times; this is reflected in the relative and absolute rise of σ_ε in the 1970s. A similar pattern can be discerned in other countries, although there are some differences across countries. These differences will in part be due to the inherent uncertainty that is an explicit feature of any econometric estimates such as provided by the UC-SV model (but are not captured by more simplistic measures of underlying inflation trends). They are also likely to reflect differences in circumstances and institutions across the countries in our sample. Nevertheless, at least over more recent years, the relative importance of the volatility of the permanent shocks has been low in all countries – σ_ε remained below σ_η – and the estimated level of σ_ε has been generally low relative to the uncertainty surrounding the estimate (see Table E1). This means that it is difficult to distinguish between different policy regimes based on the behaviour of the permanent component of inflation.

Figure 3: Ratio of the Standard Deviation of the Permanent Shocks to the Sum of the Standard Deviations of the Temporary and Permanent Shocks



In order to shed more light on possible differences between IT and non-IT countries, we can compare estimates of the distribution of the permanent component of inflation across these two groups over time. Specifically, we look at four time periods: one before, one around, and two after the introduction of inflation targeting (exactly which dates we look at does not affect the key conclusions from this exercise).[11] At any point in time, we have an estimate of the distribution for the standard deviation of the permanent component of inflation (the median of each of these is shown in Figure 2 above). So, it is straight forward to combine these distributions across countries within the IT and non-IT groups, assigning equal weight to all countries within each group, as shown in Figure 4.

Figure 4: Estimated Density for Standard Deviation of the Permanent Component (σ_{ε})



From this figure we can see some evidence that after 1993 the distribution of the standard deviation of the permanent shocks to inflation narrowed, particularly

[11] The adoption date of inflation targeting varies from country to country. Kuttner (2004) dates inflation targeting to have begun in: Australia in March 1993; Canada in February 1991; New Zealand in December 1989; Sweden in January 1993; and the UK in October 1992. All had adopted the inflation-targeting framework by 1993:Q1. Classifying countries as inflation and non-inflation targeters can seem a bit arbitrary, particularly for countries in Europe in the run-up to monetary union, which entailed explicit targets for inflation.

for IT countries. This suggests that inflation targeters became better at managing shocks hitting the economy than in the past (including, perhaps, by contributing less to monetary policy shocks) and are now comparable to non-targeters, who also improved on this score. This is consistent with Truman (2003), who finds IT countries experienced larger declines in inflation volatility, but with differences in initial conditions for IT and non-IT countries. Of course, caution should be used in interpreting the results. For example, we are unable to determine the extent to which these changes were simply due to good luck.

4. Forecastability of Inflation

Low and stable inflation should imply that inflation is relatively easy to forecast. So it makes sense when comparing outcomes in IT and non-IT economies to consider how easy it is to forecast inflation, particularly over horizons of about two years, by which time monetary policy could be expected to have had time to control inflation in response to a particular shock. In this section of the paper we compare the accuracy of out-of-sample forecasts across countries and over time within countries using different models. As discussed above, using the UC-SV model in this way is potentially problematic, notwithstanding its within-sample fit. We pay particular attention to comparing the out-of-sample forecasting performance of the UC-SV and M-UC-SV models.

In this exercise we estimate each model using data available at a given date t, and computing a h-period-ahead forecast for date $t+h$, then moving forward one period (to $t+1$), and so on. We use a rolling ten-year window to estimate the models and generate inflation forecasts for eight quarters in the future.[12] For each model, this gives us a series of forecast errors for each country. These series are then pooled together for inflation targeters and non-targeters; in order to compare how the forecasting performance has changed over time we split the 48-year sample in half.

Table 3 summarises the results of this out-of-sample forecasting exercise, and disaggregates these results according to monetary policy regime. For both models, the root mean squared error (RMSE) fell substantially from the first to the second

[12] The permanent component of inflation provides a h-period-ahead forecast measure of inflation ($\pi_{t+h|t} = \tau_{t|t}$) for the UC-SV model. In the autoregressive version, the forecast is an exponentially weighted average of the persistent deviation τ_t and the permanent level μ.

half of the sample period, indicating that inflation became much easier to forecast. IT countries experienced a slightly better improvement in RMSE compared to non-IT countries, but, on average, forecast errors remain slightly smaller in the non-IT country sample.

Table 3: Root Mean Squared Errors
Per cent – annualised

		1977–1992	1993–2008
Inflation targeters	UC-SV	4.53	2.19
	M-UC-SV	4.61	2.29
Non-targeters	UC-SV	3.34	1.63
	M-UC-SV	3.38	1.55

Figures 5 and 6 plot the actual change in inflation against the forecasted change. Because there are too many data points for a scatterplot to be meaningful, we show the contours of kernel density estimates instead. Following Theil (1966), the plots focus on the forecast of the *change* in inflation, rather than the forecast of its level, for several reasons: this puts the focus on predicting turning points, which is both harder and arguably more useful than predicting a continuing trend; it circumvents the problem of rescaling and demeaning the observations; and it makes it easy to visualise the naïve forecast ($\Delta\pi_{t+8} = 0$) that we use as a benchmark. To interpret these, note that a naïve forecast (which has $\pi_{t+8|t} = \pi_t$) would generate points along the horizontal axis, while a perfect forecast would be a 45° line through the origin. The solid line shows the line of best fit through each set of points. The gradient of this line of best fit is comparable to the forecastability measures of Theil (1966). It indicates how far the model's average performance is from that of a perfect forecasting model, with a value of one corresponding to perfection and a value of zero indicating failure.

These figures confirm that inflation became easier to forecast from the first half of the sample to the second; both lines of best fit for each model are closer to the 45° line. Overall, it seems that the M-UC-SV model's forecasts are less biased, at the cost of lower precision. This is evidenced by the fact that its line of best fit (solid line) is steeper than that of the UC-SV (M-UC-SV forecasts are more accurate on average), while the contours around these solid lines are wider (M-UC-SV forecasts are less precise). In other words, the UC-SV's forecasts of

Figure 5: Forecasting Performance

1977–1992

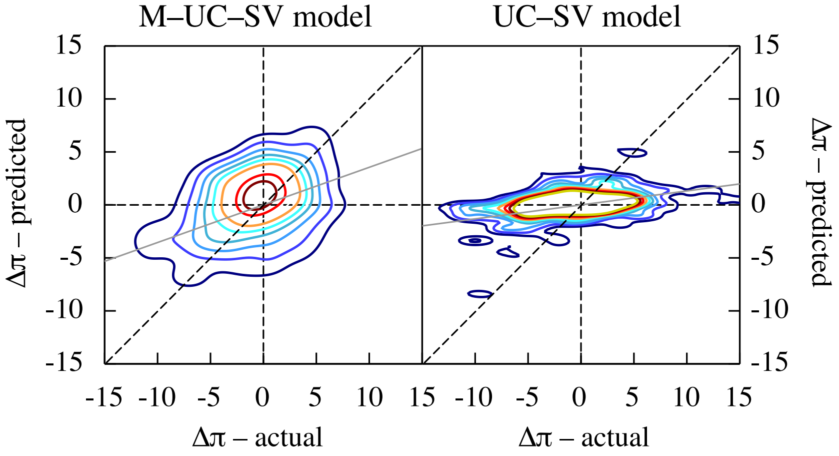
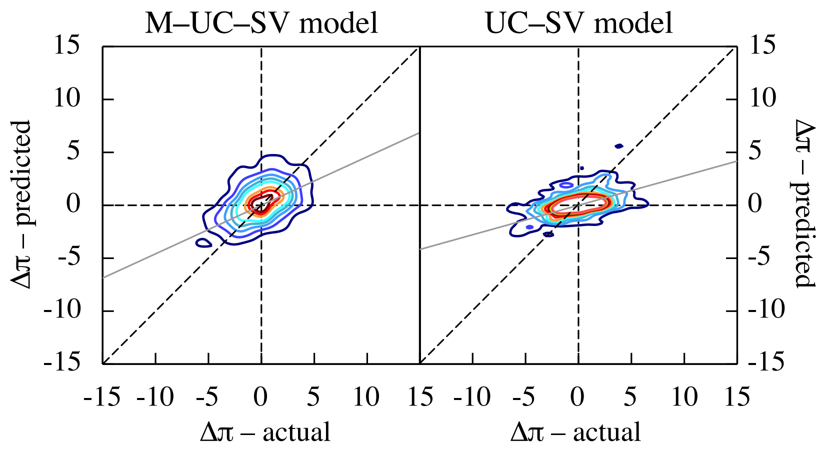


Figure 6: Forecasting Performance

1993–2008



$\Delta\pi_{t+8}$ are biased towards zero. The bias for both models is somewhat lower in the latter period of low and stable inflation.

Table 4 reports the slope of the line of best fit, calculated as for Figures 5 and 6. The results suggest that inflation became easier to forecast across the board.

In order to investigate more carefully the relative performance of the UC-SV model and its M-UC-SV version, we provide a country-by-country breakdown of the forecast performance in Table 5, based on the RMSE. Table 5 also reports the forecast performance of a naïve forecast for inflation eight quarters in the future ($\pi_{t+8|t}$) based on the most recently observed value (π_t). In other words, it always predicts no change in inflation. We also present the RMSEs of a

Table 4: The Bias of Inflation Forecasts

		1977–1992	1993–2008
Inflation targeters	UC-SV	0.16	0.29
	M-UC-SV	0.37	0.46
Non-targeters	UC-SV	0.07	0.29
	M-UC-SV	0.34	0.50

Note: The bias is measured by the slope of the line of best fit for $\Delta\pi_{t+8|t}$ regressed on $\Delta\pi_{t+8}$.

benchmark provided by the Atkeson and Ohanian (2001) (AO) model, whereby the eight-quarter-ahead inflation rate is forecast as the average rate of inflation over the previous four quarters.[13]

We chose the AO model as a benchmark as it is hard to beat.[14] Consider two extremes. If inflation were a random walk, the best forecast would be the current value of inflation (the naïve method), but the AO model would also do reasonably well. In contrast, if inflation was subject only to purely transitory shocks, the naïve method would do poorly, while again the AO model should do reasonably well. The M-UC-SV model should perform relatively well in situations where inflation experiences persistent (but not permanent) deviations from a relatively stable mean. Also, one advantage of the UC-SV and M-UC-SV models is that they can accommodate changes in the volatility of the persistent and transitory components.

Together, the two models outperform the AO benchmark in most countries in both sample periods. For Australia in the more recent sample period, the AO model performs best, and across all models the RMSE for Australia is comparable to those of Austria, Japan, the United Kingdom and the United States, and lower than for Canada, New Zealand and Sweden. Across all countries, the performance of the M-UC-SV is comparable to that of the UC-SV model. Excluding the countries

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[13] Here we follow Stock and Watson's (2007) interpretation of Atkeson and Ohanian (2001).

[14] Stock and Watson (2007, 2008) provide a comprehensive review of the forecasting performance of many inflation models (a total of 157 distinct models). They report that there is no single model, nor combination of univariate models, that has uniformly better performance than the UC-SV model, at least for quarterly US data. Canova (2007) focuses on CPI inflation in G7 countries and finds that the performance of univariate time-varying parameter models is hardly any different than that of more complicated model specifications.

Table 5: Root Mean Squared Errors

		1977–1992	1993–2008
Australia	AO	4.23	1.67
	Naïve	4.51	2.24
	UC-SV	3.77	1.81
	M-UC-SV	4.05	2.10
Austria	AO	2.57	1.70
	Naïve	3.09	2.08
	UC-SV	2.81	1.64
	M-UC-SV	2.34	1.56
Canada	AO	3.44	2.51
	Naïve	3.63	3.11
	UC-SV	3.46	2.45
	M-UC-SV	4.30	2.48
France	AO	3.37	1.37
	Naïve	3.43	1.76
	UC-SV	3.32	1.34
	M-UC-SV	4.53	1.54
Germany	AO	2.64	1.84
	Naïve	2.75	2.27
	UC-SV	2.65	1.82
	M-UC-SV	2.60	1.61
Japan	AO	3.63	1.80
	Naïve	3.86	2.16
	UC-SV	3.56	1.73
	M-UC-SV	3.17	1.56
NZ	AO	6.10	2.14
	Naïve	6.83	2.42
	UC-SV	6.62	2.14
	M-UC-SV	5.56	2.17
Sweden	AO	4.74	2.85
	Naïve	5.69	2.91
	UC-SV	4.59	2.86
	M-UC-SV	5.09	2.96
UK	AO	3.10	1.69
	Naïve	3.55	1.59
	UC-SV	3.35	1.44
	M-UC-SV	2.72	1.53
US	AO	2.06	1.60
	Naïve	4.21	1.85
	UC-SV	4.12	1.57
	M-UC-SV	3.78	1.47

where both models fail to beat the AO benchmark, the M-UC-SV is preferred to the UC-SV model in a majority of countries.

The ability of these models to outperform the AO benchmark in a range of countries is evidence against the conclusions of recent econometric studies (including Stock and Watson 2007). That literature suggests that inflation became easier to forecast in the sense that the size of RMSEs had fallen (as in Table 3 above) *and* that more stable inflation makes the AO model a harder benchmark to beat. By contrast, in our second sample period, the AO model is clearly superior in only one out of ten countries; the last few years of the sample show a rise in the persistent component of inflation for most countries, which the UC-SV and M-UC-SV models should capture better than the AO model.

5. Conclusion

This paper compares the statistical properties of inflation in a sample of IT and non-IT countries using an unobserved components stochastic volatility model (UC-SV) proposed by Stock and Watson (2007). This approach decomposes inflation into permanent and transitory components and allows the variability of both components to change over time. We find that IT countries (Australia, Canada, New Zealand, Sweden and the United Kingdom) on average experienced a more pronounced fall in the volatility of the permanent component of inflation than non-IT countries (Austria, France, Germany, Japan and the United States), to levels that are now broadly comparable.

We also propose a modification of the original UC-SV model in order to allow for more plausible implied properties of inflation which are particularly desirable when forecasting inflation. We find that inflation became easier to forecast in both IT and non-IT countries since the early 1990s, but forecast errors remained somewhat smaller in the latter group. Across the countries in our sample, forecasts from the modified UC-SV model are generally superior to those based on the assumption that the eight-quarter-ahead inflation rate is the average rate of inflation over the previous four quarters.

Appendix A: Data Description and Sources

Australia: Consumer price index excluding interest and tax, 1969–2008 (quarterly), available from the Reserve Bank of Australia. Mortgage interest charges were removed from the published CPI basket in 1998:Q3; we used a recalculated headline series that removed those charges from the earlier part of the sample. The introduction of a Goods and Services Tax (GST) in 2000 caused an inflationary spike that is not considered significant for the purposes of monetary policy, so we used a series that corrects for this effect. For further details on the series, see Roberts (2005) and Brischetto and Richards (2006).

Austria: CPI for average wage-earning households (Series I), 1959–2008 (monthly), available from Statistik Austria. For our analysis, we seasonally adjusted the series and then converted it to a quarterly frequency. When Austria joined the European Union in 1995, changes in food subsidies caused a drop in CPI. However, we have not corrected for this effect.

Canada: Headline CPI, 1960–2008. For our analysis, we seasonally adjusted the series. Ideally, we would correct for the effects of indirect taxes, but the published index that does this, the CPIXFET series, also excludes food and energy. For further details on the Bank of Canada's preferred inflation measure, see Laflèche and Armour (2006).

France: CPI, 1960–2008 (monthly), available from Eurostat, and from Datastream (code FRCP....F). For our analysis, we seasonally adjusted the series and then converted it to a quarterly frequency. There have been four relatively minor changes to Value Added Tax (VAT) in recent history; we did not adjust the CPI for these. (In January 1977, the VAT rate decreased from 20 per cent to 17.6 per cent; in July 1982, it increased to 18.6 per cent; in August 1995, it increased to 20.6 per cent; and in April 2000, it fell to 19.6 per cent.) The Banque de France focuses on the Harmonised Index of Consumer Prices (HICP), HICP excluding food and energy and HICP excluding administered prices. However, these series have not been included in our study, because of their short time span. Statistical measures have also been considered, but rejected for their lack of economic meaning (Bihan and Sédillot 1999).

Germany: CPI for the Federal Republic of Germany, January 1960–2008 (monthly), available from Statistisches Bundesamt Deutschland. Prior to 1991, we used West German data. For our analysis, we seasonally adjusted the series and then converted it to a quarterly frequency. Numerous changes to VAT have been made during the period under consideration, but they are likely to have had small first-round effects on inflation (Hoffmann and Hofmann 2004). The exception is the VAT change of January 2007, which had significant first-round effects; however, those effects were smoothed over a twelve-month period beginning half a year before the tax change, and were entangled with second-round effects (Deutsche Bundesbank 2008).

Japan: All Japan CPI, 1975–2008, monthly, corrected for the VAT change in April 1997. For our analysis, we seasonally adjusted the series and then converted it to a quarterly frequency.

New Zealand: GST-corrected CPI (PCPIG), 1975–2008, quarterly, available from the Reserve Bank of New Zealand; supplemented with the headline CPI (Datastream code NZCP....F) prior to 1975. The PCPIG excludes the direct price effects of the introduction of GST in 1986 and the increase in 1989. For our analysis, we seasonally adjusted the series.

Sweden: CPI, 1960–2008, available from Statistics Sweden. Indirect taxes contributed around 1.5 per cent to the monthly changes in CPI in March 1990 and January 1991 and 1993, and subtracted around 1.2 per cent from the monthly changes in CPI in January 1992. The published CPIX measure removes these effects, along with mortgage interest charges. We used the headline measure in our analysis because of its longer available span and seasonally adjusted it.

United Kingdom: Retail prices index excluding mortgage interest payments (RPIX), 1975–2008, monthly; we seasonally adjusted the series and then converted it to a quarterly frequency.

United States: CPI, 1960–2008, all urban consumers (CPI-U), seasonally adjusted, available from the bureau of Labor Statistics; converted to a quarterly frequency for our analysis.

Appendix B: Simple Measures of Inflation Behaviour

Table B1 shows a collection of simple measures that could be used to evaluate central bank performance. The 'Headline' columns are based on the year-ended growth in the data series that were described in Appendix A. The 'Core' columns use the following data series: Australia, trimmed mean CPI (15 per cent trim); Canada, CPI excluding food, energy and indirect taxes; Japan, All Cities CPI excluding fresh food; New Zealand, PCPITA, the CPI measure being targeted in a given quarter; Sweden, CPI excluding mortgage interest payments; UK, RPIX until 2003:Q2, with CPI thereafter; US, personal consumption expenditures deflator.

Table B1: Inflation Behaviour

	Mean		**Std dev**		**MAD**		**Outside band**	
	Headline	Core	Headline	Core	Headline	Core	Headline	Core
	IT countries							
Australia	2.54	2.26	0.68	0.42	0.51	0.37	25	16
Canada	2.08	1.87	1.29	0.66	0.88	0.53	17	5
NZ	2.28	2.21	1.30	0.81	1.06	0.68	26	19
Sweden	1.47	1.69	1.35	0.87	1.16	0.78	31	21
UK	2.61	2.39	0.80	0.51	0.87	0.53	22	1
	Non-IT countries							
Austria	1.94		0.85			0.68		
France	1.61		0.56			0.42		
Germany	1.73		0.93			0.66		
Japan	0.11	–0.03	0.85	0.59	0.64	0.45		
US	2.60	2.08	0.67	0.59	0.54	0.46		

Notes: Following Kuttner (2004), we chose samples that begin as follows: Australia, at 1993:Q1; Canada, at 1991:Q1; New Zealand, at 1989:Q4; Sweden, at 1993:Q1; and the UK, at 1992:Q4. The samples for non-IT countries begin in 1993:Q1. All the samples end in 2007:Q1. For a description of the various core (or underlying) measures see main text above.

The 'Mean' and 'Std dev' columns show the sample mean and sample standard deviation of inflation during the period in question. For IT countries, 'MAD' is the mean absolute deviation from the centre of the target band; and 'Outside band' is the number of quarters during which the inflation measure was outside the target, allowing for changes to the target band where appropriate. Australia targets a headline inflation rate of 2 to 3 per cent on average over the business cycle; Canada targets 2 per cent inflation in headline CPI, with a range of 1 to 3 per cent; New Zealand initially targeted a range of 3 to 5 per cent, then 0 to 2 per cent from 1992 to 1996, then 0 to 3 per cent from 1997 to 2001, then 1 to 3 per cent from 2002 onwards; Sweden targets 2 per cent inflation, with a tolerance interval of 1 per cent either side (the target, announced in 1993, became effective in 1995); and the UK initially targeted 1 to 4 per cent RPIX inflation (with an objective to be in the lower half of that range by the end of the 1992–1997 Parliament), then 2.5 per cent RPIX inflation with a tolerance interval of 1 per cent either side from 1996 to 2003, then 2 per cent CPI inflation from 2004 onwards, with a formal explanation required for deviations of more than 1 per cent either side of the target. For non-IT countries, the 'MAD' column is the mean absolute deviation from the sample mean.

Appendix C: Parameter Estimates

Table C1: Parameter Estimates

Full sample

	Mean	5%	95%	Mean	5%	95%	Mean	5%	95%
		Australia			Austria			Canada	
ϕ	0.29	0.01	0.97	0.08	0.01	0.26	0.33	0.02	0.94
μ	0.79	0.61	0.98	0.56	0.45	0.68	0.54	0.43	0.69
γ_ε	0.25	0.16	0.39	0.25	0.16	0.39	0.26	0.16	0.39
γ_η	0.28	0.18	0.39	0.34	0.24	0.39	0.36	0.29	0.39
$\gamma_\varepsilon^\star$	0.25	0.10	0.39	0.13	0.10	0.27	0.19	0.10	0.39
$\gamma_\eta^\star$	0.38	0.37	0.39	0.39	0.37	0.39	0.38	0.36	0.39
		France			Germany			Japan	
ϕ	0.32	0.01	0.98	0.17	0.02	0.66	0.90	0.70	0.98
μ	0.54	0.34	0.80	0.44	0.36	0.53	0.17	-0.08	0.46
γ_ε	0.26	0.16	0.39	0.25	0.16	0.39	0.35	0.24	0.39
γ_η	0.32	0.23	0.39	0.36	0.29	0.39	0.39	0.37	0.39
$\gamma_\varepsilon^\star$	0.23	0.10	0.39	0.19	0.10	0.39	0.15	0.10	0.37
$\gamma_\eta^\star$	0.31	0.10	0.39	0.38	0.35	0.39	0.38	0.36	0.39
		NZ			Sweden			UK	
ϕ	0.36	0.01	0.98	0.52	0.01	0.99	0.41	0.01	0.98
μ	0.53	0.20	0.77	0.56	0.25	1.01	0.62	0.05	0.83
γ_ε	0.28	0.16	0.39	0.30	0.17	0.39	0.27	0.16	0.39
γ_η	0.36	0.28	0.39	0.38	0.33	0.39	0.26	0.12	0.39
$\gamma_\varepsilon^\star$	0.37	0.27	0.39	0.29	0.10	0.39	0.26	0.12	0.39
$\gamma_\eta^\star$	0.29	0.10	0.39	0.39	0.38	0.39	0.34	0.13	0.39
		US							
ϕ	0.09	0.01	0.26						
μ	0.62	0.52	0.74						
γ_ε	0.24	0.16	0.38						
γ_η	0.29	0.20	0.39						
$\gamma_\varepsilon^\star$	0.24	0.10	0.39						
$\gamma_\eta^\star$	0.30	0.11	0.39						

Note: * parameters are from the UC-SV model; other parameters are from the M-UC-SV model

Table C2: Parameter Estimates
1977:Q3–1992:Q4

	Mean	5%	95%	Mean	5%	95%	Mean	5%	95%
		Australia			Austria			Canada	
ϕ	0.22	0.02	0.64	0.17	0.01	0.54	0.22	0.02	0.65
μ	1.45	1.10	1.75	0.77	0.58	0.94	1.09	0.85	1.33
γ_ε	0.27	0.15	0.39	0.25	0.14	0.39	0.26	0.14	0.39
γ_η	0.19	0.10	0.35	0.22	0.11	0.38	0.20	0.10	0.35
$\gamma_\varepsilon^\star$	0.18	0.10	0.39	0.15	0.10	0.39	0.32	0.10	0.39
$\gamma_\eta^\star$	0.38	0.33	0.39	0.36	0.28	0.39	0.34	0.12	0.39
		France			Germany			Japan	
ϕ	0.25	0.01	0.96	0.43	0.04	0.93	0.18	0.01	0.64
μ	0.86	0.24	1.11	0.46	0.23	0.71	0.37	0.21	0.56
γ_ε	0.27	0.14	0.39	0.27	0.15	0.39	0.27	0.14	0.39
γ_η	0.24	0.11	0.39	0.35	0.24	0.39	0.37	0.29	0.39
$\gamma_\varepsilon^\star$	0.34	0.21	0.39	0.32	0.12	0.39	0.16	0.10	0.39
$\gamma_\eta^\star$	0.29	0.10	0.39	0.31	0.10	0.39	0.36	0.25	0.39
		NZ			Sweden			UK	
ϕ	0.51	0.03	0.98	0.18	0.01	0.58	0.21	0.02	0.68
μ	0.66	-0.19	1.49	1.52	1.19	1.83	1.37	1.14	1.62
γ_ε	0.31	0.16	0.39	0.27	0.15	0.39	0.26	0.15	0.39
γ_η	0.34	0.22	0.39	0.21	0.10	0.38	0.20	0.10	0.35
$\gamma_\varepsilon^\star$	0.37	0.32	0.39	0.27	0.10	0.39	0.38	0.32	0.39
$\gamma_\eta^\star$	0.15	0.10	0.39	0.36	0.26	0.39	0.33	0.10	0.39
		US							
ϕ	0.21	0.02	0.61						
μ	1.06	0.88	1.22						
γ_ε	0.26	0.14	0.39						
γ_η	0.19	0.10	0.34						
$\gamma_\varepsilon^\star$	0.37	0.27	0.39						
$\gamma_\eta^\star$	0.22	0.10	0.39						

Note: * parameters are from the UC-SV model; other parameters are from the M-UC-SV model

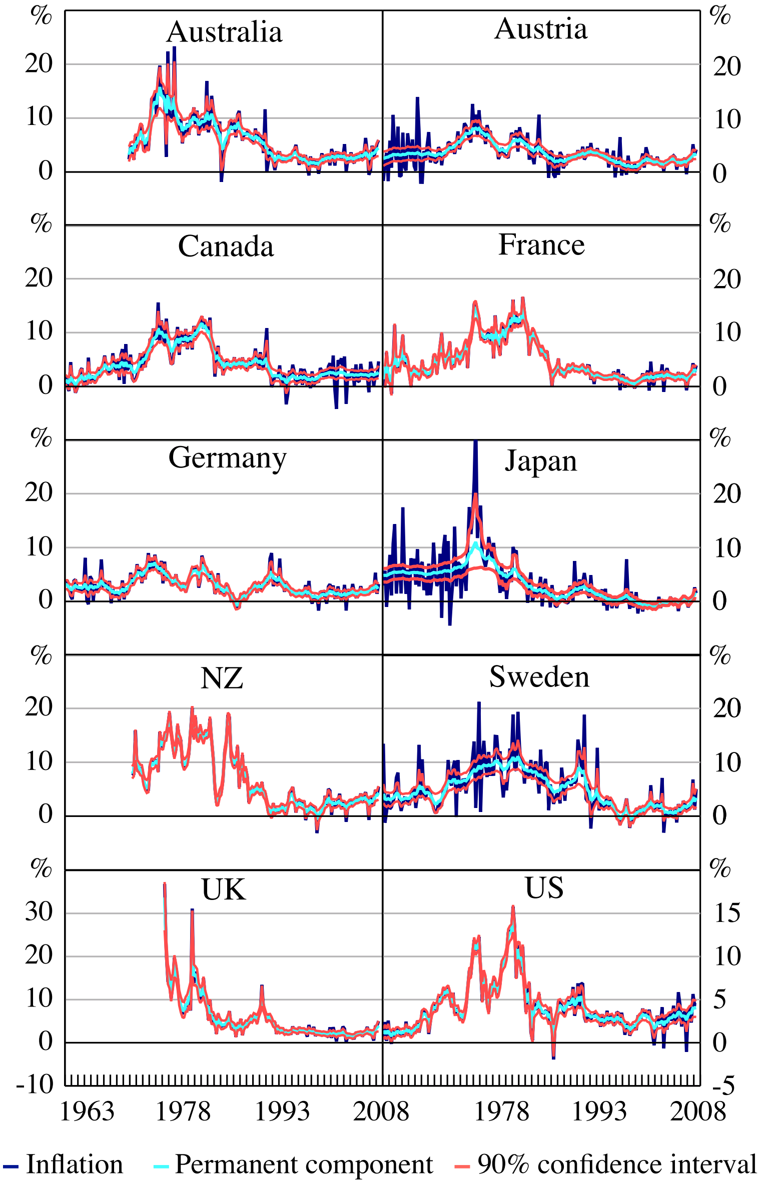
Table C3: Parameter Estimates
1993:Q1–2008:Q2

	Mean	5%	95%	Mean	5%	95%	Mean	5%	95%
		Australia			Austria			Canada	
ϕ	0.16	0.01	0.46	0.12	0.01	0.34	0.10	0.01	0.28
μ	0.60	0.49	0.71	0.39	0.27	0.50	0.40	0.26	0.53
γ_ε	0.26	0.14	0.39	0.25	0.14	0.39	0.25	0.14	0.39
γ_η	0.20	0.10	0.37	0.33	0.20	0.39	0.32	0.17	0.39
$\gamma_\varepsilon^\star$	0.11	0.10	0.18	0.12	0.10	0.22	0.11	0.10	0.14
$\gamma_\eta^\star$	0.36	0.27	0.39	0.37	0.30	0.39	0.36	0.27	0.39
		France			Germany			Japan	
ϕ	0.17	0.01	0.46	0.08	0.01	0.24	0.32	0.03	0.71
μ	0.34	0.25	0.44	0.29	0.22	0.46	-0.01	-0.08	0.07
γ_ε	0.24	0.14	0.39	0.24	0.14	0.39	0.29	0.16	0.39
γ_η	0.31	0.15	0.39	0.30	0.14	0.39	0.36	0.25	0.39
$\gamma_\varepsilon^\star$	0.12	0.10	0.19	0.12	0.10	0.23	0.12	0.10	0.19
$\gamma_\eta^\star$	0.36	0.27	0.39	0.37	0.31	0.39	0.36	0.25	0.39
		NZ			Sweden			UK	
ϕ	0.16	0.01	0.48	0.10	0.01	0.31	0.22	0.01	0.55
μ	0.50	0.37	0.63	0.23	0.10	0.35	0.58	0.50	0.66
γ_ε	0.25	0.14	0.39	0.28	0.15	0.39	0.25	0.14	0.39
γ_η	0.25	0.10	0.39	0.37	0.30	0.39	0.17	0.10	0.31
$\gamma_\varepsilon^\star$	0.24	0.10	0.39	0.22	0.10	0.39	0.11	0.10	0.15
$\gamma_\eta^\star$	0.33	0.11	0.39	0.37	0.31	0.39	0.35	0.22	0.39
		US							
ϕ	0.22	0.01	0.58						
μ	0.64	0.55	0.74						
γ_ε	0.26	0.14	0.39						
γ_η	0.16	0.10	0.31						
$\gamma_\varepsilon^\star$	0.12	0.10	0.21						
$\gamma_\eta^\star$	0.35	0.23	0.39						

Note: * parameters are from the UC-SV model; other parameters are from the M-UC-SV model

Appendix D: Inflation and its Permanent Component

Figure D1: Inflation and its Permanent Component



Appendix E: Cross-country Estimates of σ_ε

Table E1: Standard Deviation of the Permanent Component (σ_ε) by Country

	1987:Q1	1993:Q1	2000:Q3	2008:Q2
Australia	1.07	0.69	0.51	0.76
	(0.33, 2.22)	(0.33, 1.45)	(0.33, 1.11)	(0.33, 2.15)
Austria	0.53	0.43	0.45	0.53
	(0.33, 1.09)	(0.33, 0.82)	(0.33, 0.87)	(0.33, 1.20)
Canada	0.80	0.80	0.50	0.53
	(0.33, 1.63)	(0.33, 1.96)	(0.33, 1.09)	(0.33, 1.18)
France	1.12	0.51	0.45	0.67
	(0.47, 1.96)	(0.33, 0.95)	(0.33, 0.86)	(0.33, 1.65)
Germany	0.84	0.80	0.54	0.56
	(0.38, 1.47)	(0.33, 1.72)	(0.33, 1.24)	(0.33, 1.42)
Japan	0.59	0.51	0.45	0.54
	(0.33, 1.50)	(0.33, 1.09)	(0.33, 0.85)	(0.33, 1.09)
NZ	3.16	0.88	1.00	0.87
	(1.12, 5.51)	(0.33, 1.93)	(0.33, 2.33)	(0.33, 2.28)
Sweden	0.91	1.52	0.82	1.05
	(0.33, 2.13)	(0.35, 3.89)	(0.33, 1.77)	(0.33, 3.35)
UK	1.45	0.83	0.45	0.69
	(0.53, 2.64)	(0.37, 1.52)	(0.33, 0.83)	(0.33, 1.63)
US	1.15	0.53	0.49	0.64
	(0.52, 2.04)	(0.33, 0.95)	(0.33, 0.96)	(0.33, 1.65)

Note: For each date, the table shows the mean estimate of σ_ε, with the 90% confidence interval in brackets.

Appendix F: GDP Growth Statistics

Table F1: Level and Volatility of GDP Growth

	1979–2008	1979–1993	1993–2008
		GDP growth[(a)]	
Australia	3.32	2.87	3.73
Austria	–	–	2.26
Canada	2.77	2.31	3.21
France	2.25	2.53	2.04
Germany	2.06	2.66	1.56
Japan	2.45	3.75	1.26
NZ	–	–	3.59
Sweden	2.29	1.65	2.95
UK	2.42	1.87	2.96
US	2.87	2.72	3.00
Average	2.55	2.55	2.66
		Volatility of GDP growth[(b)]	
Australia	1.90	2.46	1.06
Austria	–	–	1.34
Canada	2.15	2.71	1.35
France	1.42	1.58	1.16
Germany	1.83	2.10	1.28
Japan	2.09	1.79	1.61
NZ	–	–	1.82
Sweden	2.16	2.02	1.81
UK	1.83	2.10	1.27
US	1.88	2.44	1.16
Average	1.91	2.15	1.39

Notes: (a) Growth is measured as $100ln(GDP_t/GDP_{t-4})$.
(b) Volatility is measured by the standard deviation of year-ended GDP growth.

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