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Uncertainty and UK Monetary Policy

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Abstract

This paper provides empirical evidence on the response of monetary policymakers to uncertainty. Using data for the UK since the introduction of inflation targets in October 1992, we find evidence that the impact of inflation on interest rates is lower when inflation is more uncertain and is larger when the output gap is more uncertain. These findings are consistent with the predictions of the theoretical literature.

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1) Introduction

Federal Reserve Chairman Alan Greenspan has recently commented that "Uncertainty is not just an important feature of the monetary policy landscape; it is the defining characteristic of that landscape" (Greenspan, 2003). This reflects the widespread acceptance of the importance of uncertainty for monetary policy. However, although the impact of uncertainty on monetary policy has been extensively discussed in the theoretical literature, there is very little empirical evidence on how uncertainty has actually affected the behaviour of policymakers. This paper attempts to provide some evidence on this by considering monetary policy in the UK since the introduction of inflation targets in October 1992. We develop and estimate empirical models of monetary policy responses to uncertainty over this period.

Our empirical models reflect the theoretical literature on monetary policy and uncertainty. There are two main strands to this literature. First, there are models of optimal monetary policy. Although results are sensitive to model specification, most results conform to the Brainard (1967) principle that policymakers that dislike uncertainty should respond less vigorously to variables that are more uncertain. Most work in this area uses a Taylor rule (Taylor, 1993), that is, a policy rule that relates the nominal interest rate to inflation and the output gap. There is a consensus that a Taylor rule describes how the Fed operates and is approximately optimal (see the discussion in McCallum, 1999). In the context of Taylor rules, the Brainard principle implies that the weight on inflation in the policy rule should be smaller when inflation is more uncertain. Similarly, the weight on the output gap should be smaller when the output gap is less certain (Peersman and Smets, 1999, Smets, 1999, Soderstrom, 2000, Rudebusch, 2001, Srour, 2003, Walsh, 2003 and Swanson, 2004). Some models further predict that the weight on the output gap should be larger when inflation is less certain, and vice versa (Peersman and Smets, 1999 and Swanson, 2004).

Our first empirical model of monetary policy and uncertainty reflects this strand of the literature. We extend the familiar Taylor rule by allowing the weight on inflation in the policy rule to vary over time in response to changes in the volatility of inflation and the output gap, and similarly for the weight on the output gap. This model allows us to test the proposition that greater uncertainty about inflation or the output gap reduces the response of policymakers to these variables, and whether greater uncertainty about one variable increases the response to the other.

The second strand of the literature on monetary policy and uncertainty analyses nonlinear responses to uncertainty. Meyer (1999) and Meyer et al. (2001) consider the effect of uncertainty about the true value of the natural rate of unemployment. They argue that policymakers should act more vigorously when unemployment is clearly some way from the natural rate of unemployment but should become more passive as unemployment moves closer to possible values of the natural rate. This argument is supported by, among others, Feldstein (2003) and Yellen (2003). Although this strand of the literature focuses on output gap uncertainty, the arguments also apply to inflation uncertainty. These arguments can therefore be generalised into the proposition that policymakers should respond more vigorously when variables are further from their desired or target levels, but that the transition to greater passivity should occur more quickly when uncertainty is greater.

Our second empirical model allows us to test this proposition. We consider a nonlinear monetary policy rule in which the weights on inflation and the output gap differ between an "inner regime" where inflation is close to the inflation target, and an "outer regime" where inflation is further from the target. The response of interest rates to inflation and the output gap depend on the probability of being in these regimes. We allow uncertainty about inflation and the output gap to affect the probability of being in either regime. If, for example, the weight on inflation is larger in the outer regime, then policymakers respond more vigorously to inflation when it is further from the inflation target. But if uncertainty about inflation increases the probability of being in the inner regime, then uncertainty will make policy responses more passive.

We estimate our models using data for the UK since the introduction of inflation targets in October 1992. We focus on this period because there is evidence of frequent changes in monetary policy behaviour before that date (Nelson, 2003). We first construct measures of uncertainty using the implied volatility from GARCH model estimates of inflation and the output gap. Our estimates are plausible. Uncertainty about inflation is greatest in early 1994, in the run up to the general election in May 1997, in late 2001 and in late 2002 and early 2003. Uncertainty about the output gap is most marked from early 2000 to late 2001 but is also high in early 1995.

We then estimate our models of monetary policy and uncertainty. There is clear evidence that monetary policy does respond to uncertainty and that it does so in a way that supports the predictions of the theoretical literature. Estimates of the augmented Taylor rule show that the response of policymakers to inflation is smaller when inflation is more uncertain but larger when the output gap is more uncertain; this is consistent with the Brainard principle. Estimates of the two-regime model confirm the findings of Martin and Milas (2004) that interest rates only respond to inflation in the outer regime and suggest that policymakers are targeting an inflation range rather than a precise target. We further find that the target range is wider when inflation is more uncertain but narrower when the output gap is less certain (although this latter effect is not well determined). This is consistent with the Meyer (1999) proposition that policymakers should respond more vigorously when variables are further from their target or desired levels. Our estimates suggest that the average value of the target range is 1.3%-2.8%, which further confirms the finding of Martin and Milas (2004) that the inflation targeting regime is asymmetric.

The remained of the paper is structured as follows. Section 2 explains our methodology and describes the two models of monetary policy that we estimate. Section 3 presents our estimates. Section 4 summarises our findings and offers some conclusions.

2) Methodology

Most recent models of monetary policy have used the Taylor rule (Taylor, 1993). In the context of the inflation targeting regime that has operated in the UK since October 1992, the Taylor (1993) policy rule can be expressed as

$$(1) \qquad i_t = i^* + \rho_\pi (E_t \pi_{t+1} - \pi^T) + \rho_y y_t$$

where i is the nominal interest rate, i^* is a constant[1], $E_t\pi_{t+1}$ is the inflation rate that at time t is expected for time (t+1), π^T is the inflation target, y is the output gap, ρ_π is the weight on inflation and ρ_y is the weight on output. In (1), interest rates are adjusted to keep

[1] Although i^* is normally interpreted as the equilibrium interest rate, the equilibrium rate is not identified if there is an inflation target (Judd and Rudebusch, 1998)

expected inflation close to the target and minimize the output gap; the importance of each objective is captured by the relative size of the relevant coefficient of the Taylor rule.

In practice, interest rate smoothing slows the adjustment of interest rates. This is normally modeled (Judd and Rudebusch, 1998, Rudebusch, 2002 and Castelnuovo, 2003) using the simple partial adjustment mechanism

(2) $$i_t = \rho_i i_{t-1} + (1 - \rho_i)\hat{i}_t$$

where $\hat{i}_t$ is the equilibrium interest rate, which is given by (1). The resulting model is

(3) $$i_t = \rho_i i_{t-1} + (1 - \rho_i)\{i^* + \rho_\pi (E_t \pi_{t+1} - \pi^T) + \rho_y y_t\}$$

In order to capture the effects of uncertainty we extend the Taylor rule as

(4) $$i_t = \rho_{it} i_{t-1} + (1 - \rho_i)\{i^* + \rho_{\pi t} (E_t \pi_{t+1} - \pi^T) + \rho_{yt} y_t\}$$

where $\rho_{it} = \rho_i + \rho_i^\pi \sigma_{\pi t} + \rho_i^y \sigma_{yt}$, $\rho_{\pi t} = \rho_\pi + \rho_\pi^\pi \sigma_{\pi t} + \rho_\pi^y \sigma_{yt}$, $\rho_{yt} = \rho_y + \rho_y^\pi \sigma_{\pi t} + \rho_y^y \sigma_{yt}$ and $\sigma_{\pi t}$ and σ_{yt} are measures of uncertainty over inflation and the output gap respectively. In equation (4), the Taylor rule coefficients vary over time in responses to changes in uncertainty. This model can be used to test whether the predictions of the literature on optimal responses to uncertainty are reflected in the behaviour of policymakers. If, as the theoretical literature suggests, increased uncertainty leads to a more passive response to a variable[2], then $\rho_\pi^\pi < 0$ and $\rho_y^y < 0$. If increased uncertainty about one variable strengthens the response to others, then $\rho_\pi^y > 0$ and $\rho_y^\pi > 0$. The theoretical literature does not discuss the smoothing parameters, but we might expect $\rho_i^\pi > 0$ and $\rho_i^y > 0$.

Our second empirical model allows for nonlinear behaviour. Consider the policy rule

(5) $$i_t = \theta_t M_t^I + (1-\theta_t) M_t^O$$

where

(6) $$M_t^I = \rho_i^I i_{t-1} + (1-\rho_i^I)\{\rho_\pi^I (E_t\pi_{t+1} - \pi^T) + \rho_y^I y_t\}$$

(7) $$M_t^O = \rho_i^O i_{t-1} + (1-\rho_i^O)\{\rho_\pi^O (E_t\pi_{t+1} - \pi^T) + \rho_y^O y_t\}$$

and

(8) $$\theta_t = pr\{\pi^L{}_t \le E_t\pi_{t+1} - \pi^T \le \pi^U{}_t\}$$

We model (8) using the quadratic logistic function

(9) $$\theta_t = pr\{\pi^L{}_t \le E_t\pi_{t+1} - \pi^T \le \pi^U{}_t\} = 1\text{-} \frac{1}{1+e^{-\gamma(E_t\pi_{t+1}-\pi^T-\pi_t^L)(E_t\pi_{t+1}-\pi^T-\pi_t^U)}}$$

This is a flexible parameterisation of the probability of being in the outer regime. The curvature of the function[3] is captured by the parameter γ. Combining (5)-(8) we have

(10) $$\begin{aligned} i_t &= (\theta_t\rho_i^I + (1-\theta_t)\rho_i^O) i_{t-1} + (1-\theta_t\rho_i^I - (1-\theta_t)\rho_i^O) \\ &\{(\theta_t\rho_\pi^I + (1-\theta_t)\rho_\pi^O)(E_t\pi_{t+1} - \pi^T) + (\theta_t\rho_y^I + (1-\theta_t)\rho_y^O) y_t\} \end{aligned}$$

Equation (10) is a nonlinear monetary policy rule in which the response of policymakers to inflation and the output gap depends on how close inflation is to the target. When inflation is expected to be close to the target, θ is larger, the inner regime is dominant and the behaviour of policymakers if captured by the ρ^I

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[2] Greenspan (2003) and Yellen (2003) discuss instances where monetary policy responded more strongly to uncertainty. Occasional departures from the Brainard principle can be rationalised in some cases (Soderstrom, 2000).

[3] θ_t becomes constant as $\gamma \rightarrow 0$ and tends to the binary function $\theta_t = 0$ if $E_t\pi_{t+1} - \pi^T < \pi^L{}_t$ or $E_t\pi_{t+1} - \pi^T > \pi^U{}_t$ and $\theta_t = 1$ if $\pi^L{}_t < E_t\pi_{t+1} - \pi^T < \pi^U{}_t$ as $\gamma \rightarrow \infty$ (Jansen and Teräsvirta, 1996).

parameters. By contrast, behaviour is captured by the ρ^O parameters when inflation is expected to be further from the target. If $\rho_\pi^I < \rho_\pi^O$ and $\rho_y^I > \rho_y^O$, then policymakers are relatively more responsive to output in the inner regime and more responsive to inflation in the outer regime[4]. To introduce uncertainty to this model, we assume

(11) $$\pi_t^L = \pi^L + \pi_\pi^L \sigma_{\pi t} + \pi_y^L \sigma_{yt}$$

and

(12) $$\pi_t^U = \pi^U + \pi_\pi^U \sigma_{\pi t} + \pi_y^U \sigma_{yt}$$

If greater uncertainty about inflation leads to a reduced response to inflation, then $\pi_\pi^U > 0$ and $\pi_\pi^L < 0$. In this case, greater uncertainty widens the bounds to the inner regime leading, ceteris paribus, to a greater weight on the inner regime where the response to inflation is weaker. Meyer's (1999) proposition that uncertainty about the output gap should lead policymakers to be less responsive to output corresponds to $\pi_y^U < 0$ and $\pi_y^L > 0$; in this case uncertainty about output will increase the weight on the outer regime where the response to output is lower.

3) Empirical Results

We use quarterly UK data for 1992Q3-2003Q3. We focus on this period because there is evidence of frequent changes in monetary policy behaviour before the introduction of inflation targets in October 1992 (Nelson, 2003). We use the 3 month treasury bill rate as the nominal interest rate (this has a close relationship with the various interest rate instruments used over this period; see Nelson, 2003), inflation is the annual change in the retail price index and output is GDP. We model the output gap as the difference between

[4] This type of policy rule can in principle be derived using the zone preferences proposed by Orphanides and Weiland (2000).

output and a Hodrick and Prescott (1997) trend. Unit root tests show that the interest rate, inflation and the output gap are all stationary.

We use the implied volatility of inflation and the output gap from GARCH models to measure uncertainty. We experimented with different GARCH representations and our preferred specifications are reported in Table 1. For inflation, we report a Phillips curve with an ARCH(1) component, whereas for the output gap we report a univariate model with an ARCH(1) component. Notice, that the conditional variance for inflation and output are generated regressors that measure with noise the true but unobserved regressors (see e.g. Pagan, 1984 and Pagan and Ullah, 1988). The estimates can be biased and inconsistent if the ARCH-type models employed are misspecified. To check this, we follow Pagan and Ullah (1988) in testing the squared residuals of the estimated ARCH models for neglected serial correlation of up to order 4. The Lagrange Multiplier (LM) F-test statistics for the ARCH model of inflation and the output gap reported at the bottom of Table 1 suggest no evidence of misspecification. Therefore, our ARCH models capture adequately the conditional heteroscedasticity present in the inflation and output data for the UK. We estimated a variety of other GARCH models to assess the robustness of our estimates. These alternative models had similar patterns of volatility, so we are confident that our measures of uncertainty are robust. The volatility of inflation and the output gap are presented in figures 1 and 2. Uncertainty about inflation is most marked in early 1994, after the general election of mid-1997, in late 2001 and in late 2002 and early 2003. Uncertainty about the output gap is greater from early 2000 to late 2001 and is also high in early 1995.

Estimates of the simple Taylor rule model of monetary policy in (3) are presented in column (i) of Table 2. We treat inflation and the output gap as endogenous, replacing expected future inflation with actual future inflation and use lagged variables as instruments for inflation and the output gap. The estimates indicate that interest rates increase by 1.65 percentage points in response to a 1 percentage point excess of inflation over the inflation target and increase by 0.54 percentage points in response to a 1 percentage point excess of output over equilibrium output (the output gap is not statistically significant). The estimated residuals appear to be white noise. However the model does fail the parameter stability test. We also note that the residuals are relatively large in late 1999 and after 2002Q1, which are periods of greater uncertainty.

Estimates of the augmented Taylor rule model in (4) are presented in column (ii) of Table 2. After removing insignificant effects, we obtained a simplified model whose estimates are presented in column (iii)[5]. The inclusion of measures of uncertainty improves the fit of the model and the estimates in columns (ii) and (iii) pass the parameter stability test[6]. We find that $\rho_{\pi}^{\pi} < 0$ and $\rho_{\pi}^{y} > 0$. The response of interest rates to inflation is therefore weaker when inflation is more uncertain and stronger when the output gap is more uncertain (although this latter effect is not statistically significant). These effects are consistent with the predictions of the theoretical literature. The smaller response to inflation when inflation is less certain is consistent with the Brainard principle, while the larger response to inflation when output is less certain is consistent with the predictions of Peersman and Smets (1999) and Swanson (2004).

We also estimated models based on Dolado et al. (2002) who find that inflation uncertainty had a negative impact on US interest rates for 1970-79 but has had a positive effect since 1983. Column (iv) of Table 2 reports estimates of

(3’) $$i_t = \rho_i i_{t-1} + (1-\rho_i)\{i^* + \rho_\pi(E_t\pi_{t+1} - \pi^T) + \rho_y y_t + \rho_{\sigma\pi}\sigma_{\pi t} + \rho_{\sigma y}\sigma_{yt}\}$$

This equation adds measures of inflation and output gap uncertainty to the simple Taylor rule in (3). The effects of uncertainty are insignificant, their inclusion does not affect estimates of the other parameters and this model has a higher standard error than other models and also fails the parameter stability test. We also estimated a model that added inflation and output gap uncertainty to the model in (4). We again found that these variables were not significant and that their inclusion did not substantially affect the estimates of the other parameters. We therefore conclude that the model in (4) provides a better explanation of UK monetary policy.

We next consider the nonlinear monetary policy rule in (10), estimates of which are presented in Table 3[7]. Column (i) presents estimates of a benchmark model with no uncertainty effects (imposing

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[5] The average value of $\rho_{\pi t} = \rho_\pi + \rho_\pi^\pi \sigma_{\pi t} + \rho_\pi^y \sigma_{yt}$ is 1.55 for the estimates in column (ii) and 1.73 for the estimates in column (iii). These are similar to the estimate of ρ_π in column (i), showing that introducing uncertainty does not affect the average estimated response to inflation.

[6] We also estimated models that imposed $\rho_\pi^y = 0$ and both $\rho_\pi^y = 0$ and $\rho_y = 0$. These models explained the data less well than the estimates presented in Table 2.

[7] Estimates of γ are poorly determined. This is consistent with van Dijk et al. (2002) who argue that the likelihood is very insensitive to this parameter.

$\pi_\pi^U = \pi_y^U = \pi_\pi^L = \pi_y^L = 0$). In initial estimates, the output gap was insignificant in the outer regime while inflation was insignificant in the inner regime. We therefore imposed $\rho_\pi^I = \rho_y^O = 0$.

The estimates suggest that policymakers only respond to inflation in the outer regime and therefore appear to be targeting an inflation range[8] of 1.3%-2.8% rather than a precise inflation target. The target range is asymmetric as the upper bound lies only 0.26% above the target of 2.5% while the lower bound is 1.24% below the target. Martin and Milas (2004) estimated a similar model for the shorter sample 1992Q4 to 2000Q1. They concluded that policymakers were targeting an inflation range of 1.4%-2.6%.

Estimates that allow for the effects of uncertainty are presented in column (ii). The estimates in column (iii) impose $\pi_y^U = \pi_y^L = 0$. The estimates in columns (ii) and (iii) fit the data better than the estimates in Table 2 and all specifications pass the stability test. The estimates of the parameters of the policy rules M_t^I and M_t^O are similar across Table 3. We find that $\pi_\pi^L < 0$ and $\pi_\pi^U > 0$. This implies that greater uncertainty about inflation widens the gap between the upper and lower bounds. Ceteris paribus, this increases the probability of being in the inner regime and so reduces the response of interest rates to inflation. This is consistent with the argument of Meyer (1999) that policymakers should respond more vigorously to uncertain variables when they are further from their equilibrium values. In column (ii) we find $\pi_y^U < 0$ and $\pi_y^L > 0$. As with the estimates in Table 2, these estimates are, although not statistically significant, consistent with the proposition that greater uncertainty about the output gap implies a stronger response to inflation.

We estimated a variety of alternative models in order to assess the robustness of our findings (these estimates are not reported but are available on request). We measured uncertainty using a four-quarter moving average of our volatility measures in order to see whether policymakers responded to a smoother measure of uncertainty. The estimates were similar but explained the data less well. We also estimated a version of the nonlinear policy rule in which our uncertainty measures were included in M^I and M^O as independent regressors. However these were insignificant. We also estimated models in which monetary policy was assumed to look more than one period ahead. Models that used $E_t\pi_{t+2}$ or $E_t\pi_{t+3}$ instead of $E_t\pi_{t+1}$ gave similar results to those reported in Table 3, although the latter estimates were less well determined. A model that used $E_t\pi_{t+4}$ was not successful. We also experimented with models that proxied the output gap using the fitted values of a regression of output on a quadratic trend. The estimates are similar to those reported in Tables 2 and 3, although the effect of uncertainty about the output gap is less well determined. On balance, it appears that our estimates are robust.

Comparing Tables 2 and 3 it is apparent that our estimates have several features in common. The effect of inflation is better determined than that of the output gap. The effect of inflation uncertainty is also well determined, whereas the effect of uncertainty about the output gap is not. Uncertainty about the inflation rate reduces the response of interest rates to inflation in both cases, while uncertainty about the output gap increases inflation response. This similarity is reflected in the close relationship between the fitted values of the interest rate calculated using the estimates in columns (iii) of Tables 2 and 3. The correlation between the series is 0.98 (the correlation between both fitted values and the actual interest rate is 0.95) and we cannot reject the hypothesis that they have the same mean and variance. The difference between the series is not statistically significant and only exceeds 2 basis points in late 1997, when inflation is more volatile and in late 2000, when the output gap was more volatile. In general, the model in column (iii) of Table 3 dominates when inflation is more uncertain, while the model in column (iii) of Table 2 dominates when the output gap is more uncertain (this is plausible since the model in column (iii) of Table 3 excludes the effect of output gap uncertainty).

We can illustrate the effects of uncertainty by using our estimates to construct counterfactual measures of what interest rates would have been if there had been no uncertainty. We do this by constructing the fitted values of the interest rate from estimates of column (iii) of Tables 2 and 3 where we set $\sigma_{\pi t} = \sigma_{yt} = 0$. For the model in column (iii) of Table 2, we calculate [9]

(13) $$\hat{i}_T^1 = \hat{\beta}_0 + \hat{\rho}_i i_{t-1} + (1-\hat{\rho}_i)\{\hat{\rho}_\pi (E_t \pi_{t+1} - \pi^T) + \hat{\rho}_y y_t\}$$

where a ^ denotes the corresponding estimate in column (iii) of Table 2. $\hat{i}_T^1$ is therefore the interest rate implied by the estimates in column (iii) of Table 2 that would have been observed if there had been no uncertainty and so $\sigma_{\pi t} = \sigma_{yt} = 0$ for all t. For the model in column (iii) of Table 3 we calculate

(14) $$\begin{aligned}\hat{i}_t^2 &= (\hat{\theta}_t \hat{\rho}_i^I + (1-\hat{\theta}_t)\hat{\rho}_i^O) i_{t-1} + (1-\hat{\theta}_t \hat{\rho}_i^I - (1-\hat{\theta}_t)\hat{\rho}_i^O) \\ &\{(1-\hat{\theta}_t)\hat{\rho}_\pi^O (E_t \pi_{t+1} - \pi^T) + \hat{\theta}_t \hat{\rho}_y^I y_t\}\end{aligned}$$

where a ^ denotes the corresponding estimate in column (iii) of Table 3 and the counterfactual regime weights $\hat{\theta}$ are calculated using $\pi_t^L = \hat{\pi}^L$ and $\pi_t^U = \hat{\pi}^U$. We cannot reject the hypothesis that $\hat{i}_T^1$ and $\hat{i}_T^2$ have the same mean as i_t, suggesting that uncertainty has not affected the average level of interest rates. However we can see from figure 3, which plots $\hat{i}_T^1$, $\hat{i}_T^2$ and i_t, that uncertainty has had an appreciable effect

[8] The estimated lower bound is $\pi^T - \pi^L$=2.5-1.24=1.26% and the upper bound is $\pi^T + \pi^U$=2.5+0.26=2.76%.

[9] This is different from using the model of column (i) of Table 2. That model assumes policymakers ignore uncertainty, whereas we use a model in which policymakers respond to uncertainty and use that model to infer what interest rates would have been had there been no uncertainty.

on the pattern of interest rates over time. Considering $\hat{i}_T^1$, we note that the largest gaps between actual and counterfactual interest rates occur in early 1995 (when output uncertainty was high), in late 1997 (possibly reflecting the South East Asian crisis that began in July 1997), in early 1999 (possibly reflecting the Russian crisis of mid-late 1998 or the introduction of the Euro in January 1999) and in late 2001 (reflecting the events of September 11 2001 and possibly the US economic situation). These differences are less marked in the case of $\hat{i}_T^2$, but the effects of uncertainty are clear in early 1999 and since late 2001.

4) Conclusions

This paper has estimated the impact of uncertainty on monetary policy using data for the UK since the introduction of inflation targets in October 1992, using two rather different models. We have found clear evidence that monetary policy has been affected by uncertainty and that these effects are consistent with the predictions of the theoretical literature. Both models suggested similar effects from uncertainty. We related the effects of uncertainty to the 1997 Asian crisis, the Russian crisis of 1998, the introduction of the Euro in 1999, the slowdown in the US economy over the past few years and the terrorist attacks on September 11 2001.

Our work can be extended in a number of ways. This approach can be applied to other countries in order to see whether there is a clear pattern in the response of monetary policy to uncertainty. Monetary policy can also be allowed to respond to other influences. It would be interesting to analyse the response of monetary policy to uncertainty over the exchange rate and asset prices, especially house prices. We intend to address these issues in future work.

Table 1

Implied volatility models

Inflation model: $\pi_t = \pi_{t-1} + \gamma_0 y_t + \varepsilon_t$, $\sigma^2_{\pi t} = \omega_0 + \omega_1 \varepsilon^2_{t-1}$

Output gap model: $y_t = \delta_0 + \delta_1 y_{t-1} + \delta_2 y_{t-2} + \delta_3 y_{t-3} + \delta_4 y_{t-4} + \eta_t$, $\sigma^2_{yt} = \phi_0 + \phi_1 \eta^2_{t-1}$

	Inflation	Output gap
γ_0	0.197 (0.083)	
ω_0	0.291 (0.079)	
ω_1	0.253 (0.130)	
δ_0		-0.026 (0.034)
δ_1		1.325 (0.168)
δ_2		-0.592 (0.264)
δ_3		0.551 (0.207)
δ_4		-0.420 (0.112)
ϕ_0		0.047 (0.015)
ϕ_1		0.622 (0.310)
Neglected ARCH	1.14 [0.35]	0.82 [0.52]

Notes: Numbers in parentheses are the standard errors of the estimates. Neglected ARCH is the Lagrange Multiplier F test on the squared residuals for remaining serial correlation of order 4. Numbers in square brackets are the probability values of the test statistics.

Table 2

Estimates of Augmented Taylor Rules

$$
\begin{aligned}
i_t &= \beta_0 + (\rho_i + \rho_i^{\pi}\sigma_{\pi t} + \rho_i^{y}\sigma_{yt})i_{t-1} \\
&+(1-\rho_i - \rho_i^{\pi}\sigma_{\pi t} - \rho_i^{y}\sigma_{yt}) \\
&\{(\rho_\pi + \rho_\pi^{\pi}\sigma_{\pi t} + \rho_\pi^{y}\sigma_{yt})(E_t\pi_{t+1} - \pi^T) \\
&+(\rho_y + \rho_y^{\pi}\sigma_{\pi t} + \rho_y^{y}\sigma_{yt})y_t\}
\end{aligned}
$$

Sample: 1992Q4-2003Q3

IV Estimates

	(i)	(ii)	(iii)	(iv)
β_0	1.244 (0.323)	1.150 (0.313)	1.143 (0.293)	1.719 (0.729)
ρ_i	0.762 (0.056)	0.865 (0.115)	0.773 (0.051)	0.764 (0.056)
ρ_i^{π}		-0.156 (0.195)		
ρ_i^{y}		0.020 (0.149)		
ρ_π	1.646 (0.484)	9.532 (4.082)	11.700 (4.431)	1.451 (0.430)
ρ_π^{π}		-16.869 (7.257)	-19.660 (7.949)	
ρ_π^{y}		7.036 (3.983)	5.950 (3.890)	
ρ_y	0.540 (0.466)	3.152 (4.756)	0.540 (0.453)	0.644 (0.479)
ρ_y^{π}		-2.216 (7.237)		
ρ_y^{y}		-3.883 (5.317)		
$\rho_{\sigma\pi}$				-3.237 (4.560)
$\rho_{\sigma y}$				-0.399 (3.165)
Adjust. R^2	0.873	0.886	0.906	0.870
s.e.	0.380	0.360	0.351	0.386
AIC	0.987	0.999	0.862	1.062
AR	2.08 [0.09]	0.61 [0.69]	1.97 [0.85]	2.18 [0.08]
Het	1.18 [0.34]	0.49 [0.92]	0.83 [0.61]	1.10 [0.39]
ARCH	0.56 [0.68]	2.03 [0.12]	1.86 [0.14]	0.55 [0.69]
Norm	0.05 [0.97]	1.53 [0.46]	0.19 [0.91]	0.01 [0.99]

Parameter stability	5.63 [0.00]	1.81 [0.11]	2.44 [0.06]	2.91 [0.03]

Notes: Numbers in parentheses are the standard errors of the estimates. s.e. is the regression standard error. AIC is the Akaike information criterion. AR is the Lagrange Multiplier F test for residual serial correlation of up to fourth order. Het is an F test for heteroscedasticity. ARCH is the fourth order Autoregressive Conditional Heteroscedasticity F test. Norm is a Chi-square test for normality. Parameter stability is an F test of parameter stability (see Lin and Teräsvirta, 1994, and Eitrheim and Teräsvirta, 1996). Numbers in square brackets are the probability values of the test statistics.

Table 3

Estimates of quadratic logistic model

$$i_t = \theta_0 + \theta_t M_t^I + (1-\theta_t) M_t^O$$

$$M_t^I = \rho_i^I i_{t-1} + (1-\rho_i^I)\{\rho_\pi^I (E_t \pi_{t+1} - \pi^T) + \rho_y^I y_t\}$$

$$M_t^O = \rho_i^O i_{t-1} + (1-\rho_i^O)\{\rho_\pi^O (E_t \pi_{t+1} - \pi^T) + \rho_y^O y_t\}$$

$$\theta_t = 1 - \frac{1}{1+e^{-\gamma (E_t\pi_{t+1} - \pi^T - \pi_t^L)(E_t \pi_{t+1} - \pi^T - \pi_t^U)}}$$

$$\pi^L{}_t = \pi^L + \pi_\pi^L \sigma_{\pi t} + \pi_y^L \sigma_{yt}$$

$$\pi^U{}_t = \pi^U + \pi_\pi^U \sigma_{\pi t} + \pi_y^U \sigma_{yt}$$

Sample: 1992Q4-2003Q3

Nonlinear IV Estimates

	(i)	(ii)	(iii)
θ_0	1.181 (0.346)	1.577 (0.291)	1.482 (0.300)
ρ_i^I	0.748 (0.063)	0.683 (0.052)	0.698 (0.054)
ρ_π^I			
ρ_y^I	0.710 (0.534)	0.604 (0.297)	0.878 (0.298)
ρ_i^O	0.775 (0.066)	0.723 (0.051)	0.742 (0.055)
ρ_π^O	1.830 (0.581)	1.971 (0.383)	1.962 (0.436)
ρ_y^O			
π^L	-1.240 (0.580)	-1.080 (0.056)	-1.080 (0.056)
π_π^L		-0.320 (0.024)	-0.320 (0.023)
π_y^L		0.861 (0.453)	
π^U	0.255 (0.028)	0.256 (0.038)	0.256 (0.038)
π_π^U		0.732 (0.058)	0.664 (0.020)

π_y^U		-0.154 (0.101)	
γ	90.217 (100.22)	94.200 (100.21)	94.200 (100.21)
Adjust. R^2	0.884	0.902	0.902
s.e.	0.377	0.328	0.333
AIC	0.976	0.717	0.747
AR	2.99 [0.03]	2.26 [0.07]	2.30 [0.07]
Het	1.19 [0.34]	0.68 [0.73]	0.75 [0.64]
ARCH	0.83 [0.51]	0.33 [0.85]	0.35 [0.84]
Norm	1.05 [0.59]	1.21 [0.55]	0.08 [0.96]
Parameter stability	0.98 [0.47]	0.61 [0.82]	0.95 [0.45]

Notes: See the notes of Table 2. Following Teräsvirta (1994), the γ parameter is made dimension-free by dividing it by the variance of $E_t\pi_{t+1}$.

Figure 1

The volatility of Inflation

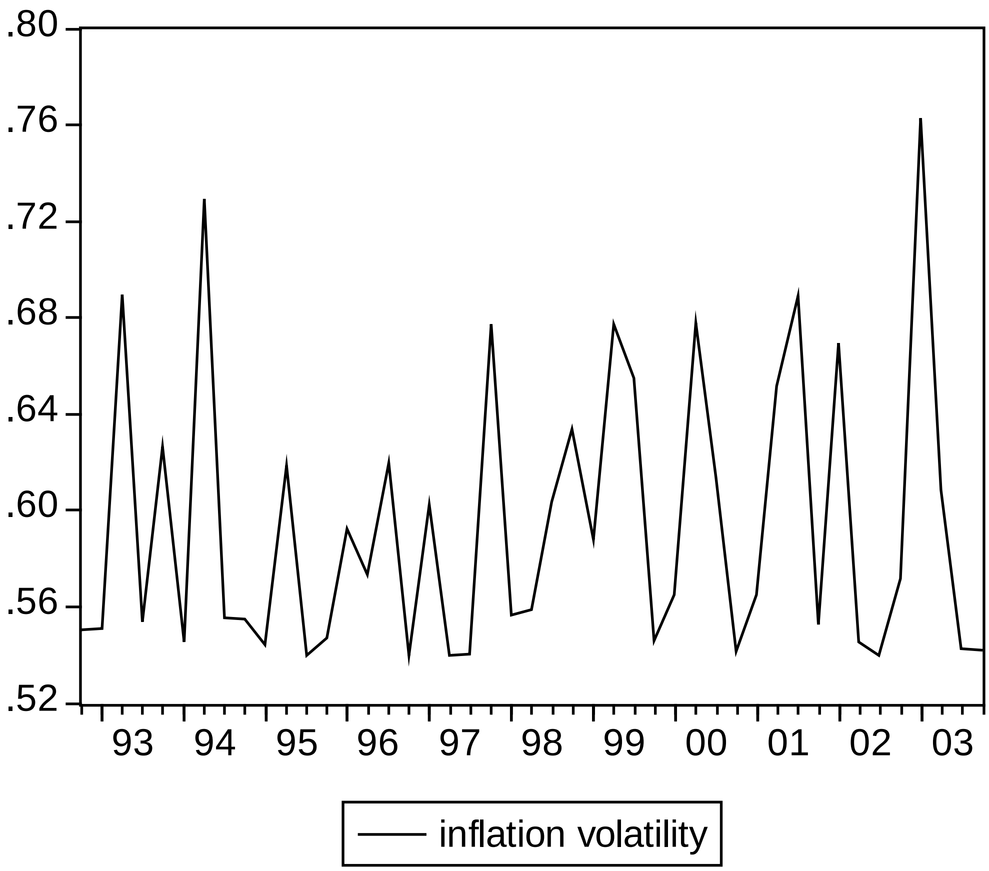


Figure 2

The volatility of the output gap

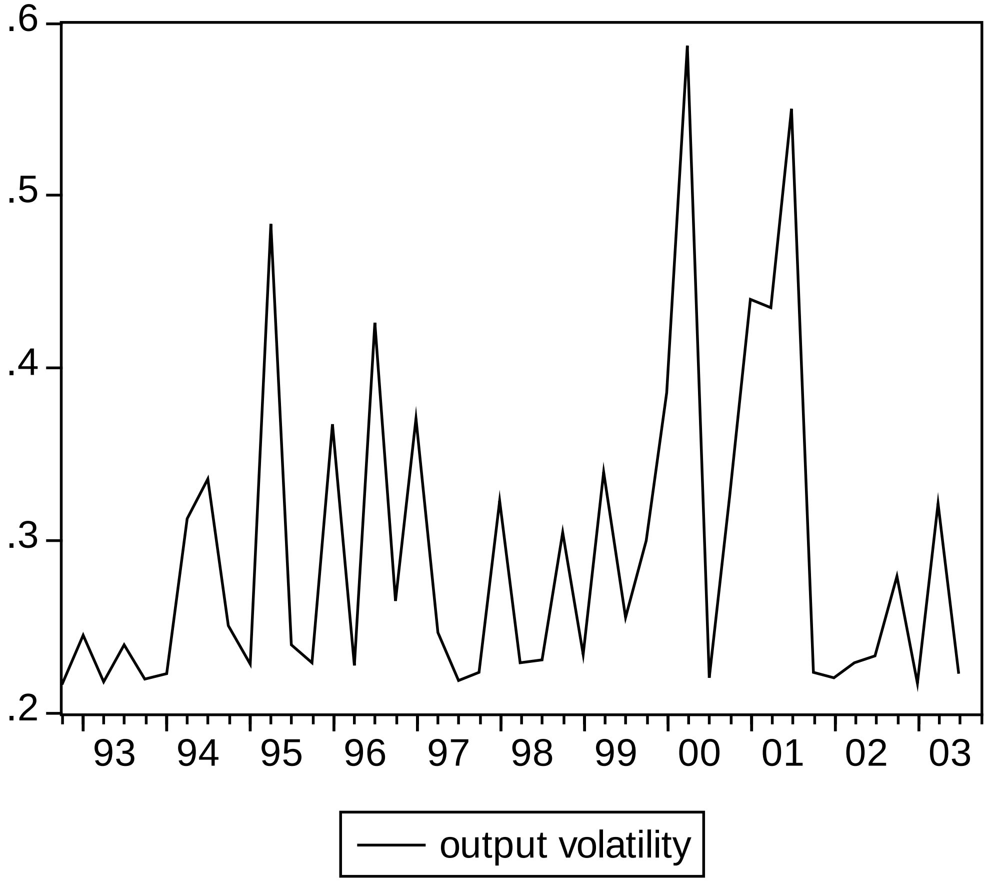
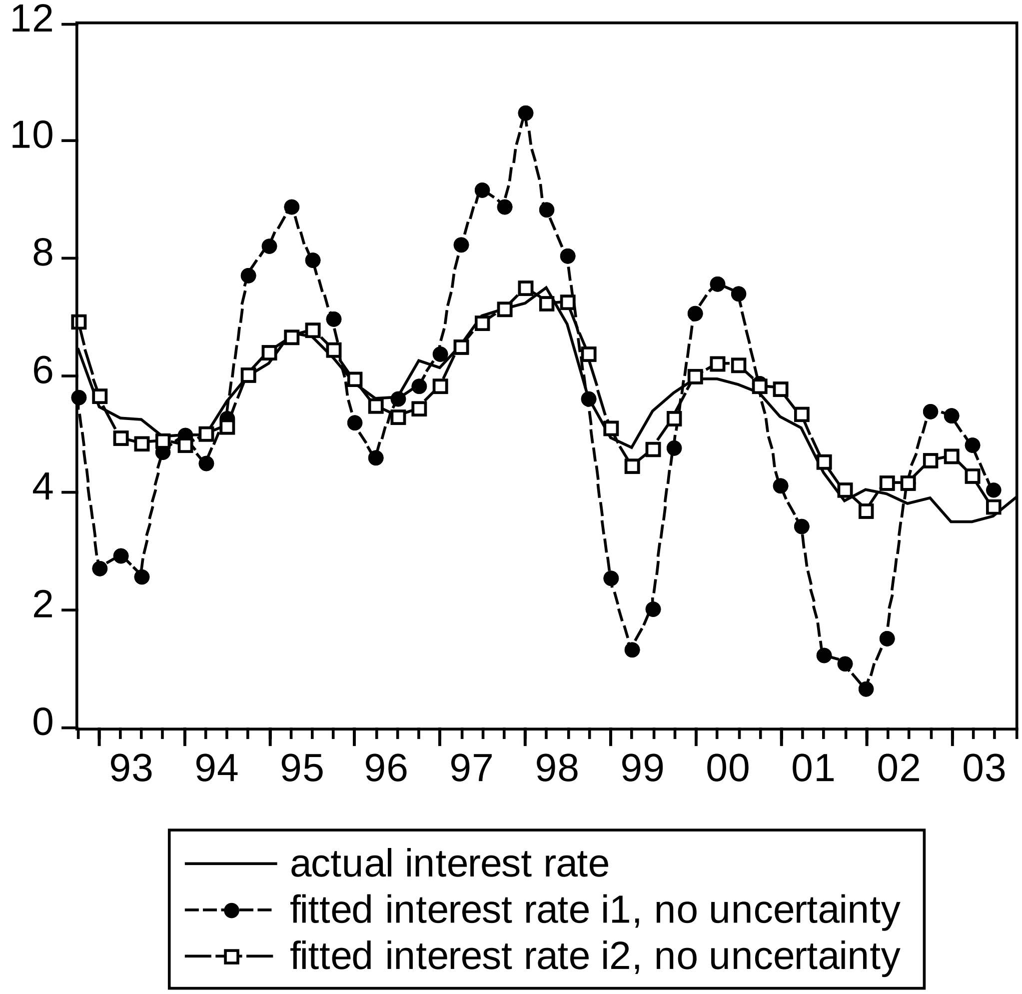


Figure 3

Fitted $\hat{i}_T^1$ and $\hat{i}_T^2$ interest rates against the actual interest rate



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