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Does high M4 money growth trigger large increases in UK inflation? Evidence from a regime-switching model

by

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Abstract March 2007 saw an increase of 3.1 percent in the Consumer Price Index (CPI) annual inflation rate and triggered the first explanatory letter from the Governor of the Bank of England to the Chancellor of the Exchequer since the Bank of England was granted operational independence in May 1997. The letter gave rise to a lively debate on whether policymakers should pay attention to the link between inflation and M4 money growth. Using UK data since the introduction of inflation targeting in October 1992, we show that: (i) the relationship between inflation and M4 growth is not stable over time, and (ii) the tendency of M4 to exert inflationary pressures is conditional on annual M4 growth exceeding 10%. Above this threshold, a 1 percentage point increase in the annual growth rate of M4 increases annual inflation by only 0.09 percentage points, whereas a 1 percentage point increase in the disequilibrium between money and its long-run determinants increases annual inflation by only 0.07 percentage points. Since the money effects are very small, the implication is that the Monetary Policy Committee should not be particularly worried for not paying close attention to M4 money movements when setting interest rates.

Keywords M4, Money growth, Regime-switching models, UK inflation

J.E.L. Class C51, C52, E52, E58

Notes I have benefited from the exchange of ideas with Tim Congdon and Chris Martin. Any remaining errors are mine.

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1. Introduction

March 2007 saw an increase of 3.1 percent in the Consumer Price Index (*CPI*) annual inflation rate and triggered the first explanatory letter from Mervyn King (Governor of the Bank of England) to Gordon Brown (Chancellor of the Exchequer) since the Bank of England was granted operational independence in May 1997. [1] The letter gave rise to a lively debate on whether policymakers should pay attention to the link between inflation and *M*4 broad money growth. For instance, in a recent letter to the *Financial Times* (dated 24 April 2007), Prof Tim Congdon along with eight other Professors and practitioners (including former external Monetary Policy Committee (MPC) member Prof Charles Goodhart) warned of a high risk of inflation following recent annual *M*4 growth rates in double digits. The letter was not left unchallenged. Sushil Wadhwani (former external MPC member) wrote in the *Times* (on 30 April 2007) that there is no reliable stable relationship between inflation and *M*4 and hinted that the open letter of explanation should become thing of the past. Current external MPC member David Blanchflower (during his Bernard Corry Memorial Lecture on 30 May 2007) repeated that the relationship between inflation and *M*4 is not constant over time and added that despite not targeting *M*4, the Bank of England will continue to monitor and analyse *M*4 developments.

Clearly, the effect of high *M*4 growth on inflation is at the centre of policy-making thinking in the UK and we contribute to this debate by quantifying the nature of the relationship since the introduction of inflation targeting in October 1992. Our main findings are summarised as follows. The relationship between UK inflation and *M*4 growth is indeed not stable over time. This should not be interpreted as evidence that UK inflation is unrelated to *M*4 movements. In fact, allowing for a more sophisticated model (in the form of regime-switching behaviour between "low" and "high" rates of money growth), this paper is able to quantify a time-varying relationship between UK inflation and money. In particular, the tendency of *M*4 to exert inflationary pressures is conditional on annual *M*4 growth being higher than the 10% threshold, which is endogenously determined by our model. Above this threshold, a 1 percentage point increase

[1] The Governor of the Bank of England must write an open letter of explanation if inflation deviates from the 2% target by more than 1%.

in the annual growth rate of *M*4 triggers a mere 0.09 percentage points increase in annual inflation, whereas a 1 percentage point increase of money above equilibrium increases inflation by only 0.07 percentage points. At the same time, the inflation effect of a 1 percentage point increase in the output gap is five times as much as the money effects above. The *M*4 effects are too small to justify claims that recent *M*4 movements (above the historical average of 8%) are highly inflationary. The implication is that the MPC do not need to be particularly worried for not paying close attention to money movements when setting interest rates.

The plan of the paper is as follows. Section 2 presents the model, discusses data issues and reports the main estimates. Section 3 reports estimates based on alternative measures of the data and specifications and Section 4 concludes.

2. Model, data and estimates

Recent models of UK inflation include Castle and Hendry (2007), Hendry (2001), Arghyrou et al (2005), Osborn and Sensier (2004), and Clements and Sensier (2003). The latter three studies consider nonlinear models but do not address the issues discussed in the current paper.

To test the existence of a meaningful relationship between *CPI* inflation and *M*4 growth [2], we use UK quarterly data between 1992q4 and 2007q1 and begin by estimating a standard backward-looking linear Phillips curve equation augmented by *M*4 monetary effects: [3]

(1) $$\Delta_4 p_t = \beta_0 + \beta_p(L)\Delta_4 p_{t-1} + \beta_{gap}(L)gap_t + \beta_{m4}(L)\Delta_4 m4_t + \beta_{diseq} diseq_{t-4} + u_t\,,$$

where p_t is the log *CPI* price level, $\Delta_4 p_t = p_t - p_{t-4}$ is the *CPI* annual inflation rate, $m4_t$ is the log *M*4 level, $\Delta_4 m4_t = m4_t - m4_{t-4}$ is the annual growth in *M*4 money, and *gap* is the output gap (given by the residuals from

[2] *M*4 consists of *M*3 (i.e. notes and coins in circulation with the public and sterling bank deposits held by UK residents) plus building society deposits again in sterling held by UK residents.

[3] The dataset comes from the National Statistics Online database, see: http://www.statistics.gov.uk/statbase/tsdlistfiles.asp

regressing log real output on a quadratic trend). $\beta_p(L)$, $\beta_{gap}(L)$ and $\beta_{m4}(L)$ are polynomials in the lag operator L, and the stochastic error term $u_t \sim i.i.d.(0,\sigma_u^2)$. In (1), lagged inflation terms proxy forward-looking expectations or rigidities in the wage price relationship resulting in lagged adjustment (see e.g. Blanchard, 1988). [4]

The money disequilibrium (*diseq*) is constructed as the residuals from the Engle and Granger (1987) long-run regression:

(2) $diseq_t = m4_t - 0.31 - 1.05 p_t - 1.24 y_t + 2.98 R_t$,

where y_t is the log level of real output, R_t is the 3-month Treasury bill and the rest of the variables have been defined above. The money disequilibrium is stationary at the 5% level. [5] To examine the robustness of our results to alternative specifications, the money disequilibrium ($diseq$) has also been estimated using a Vector Autoregressive (VAR) model with four lags in $m4_t$, p_t, y_t and R_t. The empirical results are consistent with the estimates reported in (2) above. [6] [7]

Figure 1 plots together *CPI* inflation, annual *M*4 growth, the output *gap*, and the *diseq* variable, whereas Table 1 reports *M*4, *CPI*, *gap* and *diseq*

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[4] For other versions of the Phillips curve (including a forward looking one) see e.g. Neiss and Nelson (2005). We return to this in Section 3 below.

[5] The ADF test statistics are ADF(0 lag)= -1.97, ADF(1 lag)= -2.11, ADF(2 lags)= -2.22, ADF(3 lags)= -2.28, ADF(4 lags)=-2.17. The 5% critical value is equal to 1.94.

[6] To account for our small sample, Johansen's (1988, 1995) λ-*max* and *trace* test statistics use a small sample correction (for exact mathematical formulas, see e.g. Doornik and Hendry, 2000, p.282). Both tests support the existence of one cointegrating relationship (*p*-value for λ-*max* = 0.00; *p*-value for *trace* = 0.00 using critical values from MacKinnon et al., 1999). Normalising on $m4_t$, we estimate the coefficient on p_t at 1.11, the coefficient on y_t at 1.27, and the coefficient on R_t at –2.22 (with standard errors equal to 0.235 for p_t, 0.162 for y_t, and 0.60 for R_t, respectively). Allowing for a linear deterministic trend in the cointegrating vector brings the coefficients on p_t and y_t down to 0.95, and 0.77, respectively, whereas the coefficient on R_t is estimated at –1.01. The correlations between this latter cointegrating vector (allowing for a trend) and those from the Engle-Granger method reported in (2) and the Johansen one without the trend are 0.94 and 0.97, respectively.

[7] Calza and Sousa (2003) review the long-run relationship among broad money, prices, output and the interest rate in the Euro area and elsewhere, whereas Hendry (2001) reports a money demand equation with unit coefficients on output and prices over the 1865-2000 period.

descriptive statistics. The average *M*4 annual growth is 8%, whereas the average *CPI* inflation rate is 1.8%, slightly below the 2% target. [8] The correlation between annual *M*4 growth and *CPI* inflation is only 0.20. Since 2005, however, *CPI* inflation is higher than the 2% target, at the same time when *M*4 growth exceeds its 8% average. Since 2005, the disequilibrium (between money and its long-run determinants) and the output *gap* are both rising. Indeed, the correlation between *CPI* inflation and the rest of the variables is stronger from 2005 onwards. This has triggered a debate on whether the recent increases in *M*4 are highly inflationary and whether they have contributed to the March 2007 open letter of explanation. This is related to the well-known view that inflation is a monetary phenomenon which goes back to Friedman's Quantity Theory of Money. [9]

Estimates of our preferred linear inflation model are reported in column (i) of Table 2. Our preferred specification is:

(3) $$\Delta_4 p_t = \beta_0 + \beta_p \Delta_4 p_{t-1} + \beta_{gap} gap_{t-4} + \beta_{m4} \Delta_4 m4_{t-1} + \beta_{diseq} diseq_{t-4} + u_t$$

This model was obtained from a specification search on a general model that included up to 4 lags of all variables and where the *diseq* variable was included at different lag lengths. The estimates in column (i) of Table 2 show that inflation is highly persistent (with a coefficient estimate of 0.77) and the output gap variable is statistically significant with a coefficient estimate of 0.14. Both the *M*4 and *diseq* estimates are statistically significant and equal to 0.03. The model, however, fails the parameter stability test. This is an indication that the relationship between *CPI* and *M*4 is not constant over time, and gives rise to the possibility that the relationship might be regime-switching between "low" and "high" rates of money growth (as hinted by some of the opposing arguments discussed in the Introduction). If this is true, the estimated model should fail the linearity test. We therefore test the estimated model in column (i) of Table 2 for the presence of non-linearities. The last

[8] The Bank of England targeted the Retail Price Index excluding mortgage interest payments (*RPIX*) before 2004. The target was set at 2.5%. We return to this in Section 3 below.
[9] In an excellent paper, Nelson (2007) uses extensive archival material from several countries to bring together information about Milton Friedman's views on U.S. monetary policy.

three rows of Table 2 report Hamilton's (2001) λ-test, and the λ_A and g-tests proposed by Dahl and González-Rivera (2003). Under the null hypothesis of linearity, these are Lagrange Multiplier test statistics following the χ^2 distribution (a brief description of these tests is given in the Appendix of the paper) [10]. These tests are powerful in detecting non-linear smooth transition behaviour (Dahl and González-Rivera, 2003). This is of particular interest as we shall use smooth transition specifications below. All three tests reject linearity.

Having rejected linearity, we consider a possible regime-switching relationship between *CPI* inflation and *M*4 money. [11] We consider, in turn, the possibility of regime-switching between "low" and "high" rates of money growth as well as the possibility of regime-switching between negative and positive deviations of money from its long-run equilibrium with prices, output, and the interest rate. The first regime-switching model we consider takes the form:

$$\text{(4)}\quad \begin{aligned}\Delta_4 p_t &= \beta_0 + (\beta_p^{Low}\Delta_4 p_{t-1} + \beta_{gap}^{Low} gap_{t-4} + \beta_{m4}^{Low}\Delta_4 m4_{t-1} + \beta_{diseq}^{Low} diseq_{t-4})\theta_{t-1} + \\ &+(\beta_p^{High}\Delta_4 p_{t-1} + \beta_{gap}^{High} gap_{t-1} + \beta_{m4}^{High}\Delta_4 m4_{t-1} + \beta_{diseq}^{High} diseq_{t-4})(1-\theta_{t-1}) + u_t\end{aligned}$$

where

$$\text{(5)}\quad \theta_{t-1} = prob\{\Delta_4 m4_{t-1} \le \delta^{m4}\}$$

Models (4) and (5) differ from the linear model (3) in that they allow for a regime-switching relationship between inflation and money growth depending on whether *M*4 grows above or below a certain thereshold value of δ^{m4}%, which is endogenously determined by the model. In this model, the effect of annual *M*4 growth on *CPI* inflation switches from β_{m4}^{Low} at "low" levels of

[10] We run the tests using Gauss codes obtained from Hamilton's web page at: http://weber.ucsd.edu/~jhamilto/software.htm#other. To account for the small sample, we report bootstrapped *p*-values of the three tests based on 1000 re-samples.

[11] Another possibility would be to specify a regime-switching model of inflation, which depends on positive versus negative values of the output gap. Clements and Sensier (2003) do not find such evidence in the UK.

money growth (when annual *M*4 growth is below δ^{m4}%) to β_{m4}^{High} at "high" levels of money growth (when annual *M*4 growth is above δ^{m4}%). The model also allows for the *diseq* parameter to switch from β_{diseq}^{Low} at "low" levels of money growth to β_{diseq}^{High} at "high" levels of money growth; at the same time, the inflation persistence parameter switches from β_{p}^{Low} to β_{p}^{High} and the output gap parameter switches from β_{gap}^{Low} to β_{gap}^{High} (a specification search indicated using gap_{t-1} rather than gap_{t-4} in the the "high" money growth regime). θ_{t-1} refers to the probability that annual *M*4 growth in period *t*-1 is below δ^{m4}%.

The second regime-switching model we consider takes the form:

$$\text{(6)}\quad \begin{aligned} \Delta_4 p_t &= \beta_0 + (\beta_p^{Low}\Delta_4 p_{t-1} + \beta_{gap}^{Low} gap_{t-4} + \beta_{m4}^{Low}\Delta_4 m4_{t-1} + \beta_{diseq}^{Low} diseq_{t-4})\phi_{t-4} + \\ &+(\beta_p^{High}\Delta_4 p_{t-1} + \beta_{gap}^{High} gap_{t-1} + \beta_{m4}^{High}\Delta_4 m4_{t-1} + \beta_{diseq}^{High} diseq_{t-4})(1-\phi_{t-4}) + u_t \end{aligned}$$

where

$$\text{(7)}\qquad \phi_{t-4} = prob(diseq_{t-4} \leq \delta^{diseq}\}$$

Models (6)-(7) allow for a regime-switching relationship between inflation and money depending on whether disequilibrium deviations of *M*4 from its long-run determinants are higher or lower than a certain threshold value of δ^{diseq}%, which is again endogenously determined by the model. We model the probabilities in (5) and (7) using the logistic functions (see e.g. van Dijk et al, 2002)

$$\text{(8)}\qquad \theta_{t-1} = prob(\Delta m4_{t-1} \leq \delta^{m4}\} = 1 - \frac{1}{1+e^{-\gamma^{m4}(\Delta m4_{t-1}-\delta^{m4})/\sigma(\Delta m4_{t-1})}}, \text{ and}$$

$$\text{(9)}\qquad \phi_{t-4} = prob(diseq_{t-4} \leq \delta^{diseq}\} = 1 - \frac{1}{1+e^{-\gamma^{diseq}(diseq_{t-4}-\delta^{diseq})/\sigma(diseq_{t-4})}}$$

In (8)-(9), the smoothness parameters γ^{m4}, $\gamma^{diseq} > 0$ determine the smoothness of the transition regimes. We follow Granger and Teräsvirta (1993) and Teräsvirta (1994) in making γ^{m4} and γ^{diseq} dimension-free by dividing the former by the standard deviation of annual *M*4 growth and the latter by the standard deviation of *diseq*.

The results of models (4)-(5) reported in column (ii) of Table 2 show that when annual *M*4 growth is below δ^{m4} = 9.95%, its effect on inflation is equal to 0.05 and statistically significant. The *diseq* effect is also equal to 0.05 and statistically significant. On the other hand, when annual *M*4 growth exceeds δ^{m4} = 9.95%, its effect rises to 0.09 and the *diseq* effect rises to 0.07. Therefore, when annual *M*4 growth exceeds the 10% threshold, a 1 percentage point increase in the annual growth of *M*4 has the effect of increasing inflation by 0.09 percentage points, whereas a 1 percentage point increase in the disequilibrium between money and its long-run determinants has the effect of increasing inflation by 0.07 percentage points in the short run. The output gap estimate switches from 0.16 at the "low" money growth regime to 0.49 at the "high" money growth regime; in the latter regime, a 1 percentage point increase in the output gap increases inflation by five times as much as a 1 percentage point increase in either annual *M*4 growth, or money deviations from equilibrium. Interestingly, the inflation persistence parameter switches from 0.77 at the "low" money growth regime to 0.58 at the "high" money growth one; presumably the stronger response of inflation to money movements and the output gap (also at a shorter lag length for the latter), at higher levels of money growth makes the inflation variable less persistent.

The estimated regime-switching model outperforms the model with constant parameters in column (i) in terms of diagnostic tests and there is no evidence of parameter instability (in contrast to the estimates in column (i)).

The results of models (6)-(7) reported in column (iii) of Table 2 show that when disequilibrium deviations switch from negative to positive (notice that the threshold δ^{diseq} is insignificantly different from zero), the *diseq* effect on inflation drops from 0.09 to 0.07 (the latter effect is statistically insignificant), whereas the impact of annual *M*4 growth on inflation is invariant at 0.03. In terms of diagnostics, the models in (6)-(7) offer only a slight improvement over the model with constant parameters (in terms of the parameter stability test) and are inferior to the regime-switching models in (4)-(5).

Using the estimates of models (4)-(5) (in column (ii) of Table 2) as our preferred specification, the time-varying impact of annual *M*4 money growth on inflation is given by:

(10) $\theta_{t-1}\beta_{m4}^{Low} + (1-\theta_{t-1})\beta_{m4}^{High}$

Figure 2 plots the time-varying impact of money together with annual *M*4 growth, the threshold δ^{m4} = 9.95% and the *CPI* inflation rate. Between 1992 and 1996, low *M*4 growth triggers a money effect on inflation of 0.05. The effect switches to 0.09 when *M*4 growth exceeds 9.95% in 1997-1998, and then drops back to 0.05 until 2005 when it rises again to 0.09 in line with the high *M*4 growth rates over the last part of the sample. The transition between regimes is quite rapid as suggested by the large smoothness parameter estimate of γ^{m4} = 20.10.

3. Robustness analysis

We investigate the robustness of our results by estimating (i) a purely forward-looking version of the linear model (3) in which lagged inflation $\Delta_4 p_{t-1}$ is replaced by expected future inflation for period *t*+1, $E_t\Delta_4 p_{t+1}$, and (ii) a "hybrid" Phillips curve (see e.g. Galì and Gertler, 1999) in which both lagged inflation and expected future inflation appear. We replace expected future inflation with actual future inflation and estimate by GMM using lagged values as instruments. The estimates reported in columns (i)-(ii) of Table 3 fail to identify any significant *M*4 effects; in the "hybrid" model, lagged and future inflation are found to have weights adding up to one. Parameter stability and linearity tests do not indicate any evidence of regime-switching behaviour.

We also consider a model where inflation is measured by *RPIX* (the measure targeted by the Bank of England until 2003). Using *RPIX*, the money disequilibrium (*diseq*) constructed from the residuals of the Engle and Granger (1987) long-run regression is qualitatively similar to the earlier estimates reported for model (2). Column (iii) of Table 3 reports estimates of the linear inflation model in (3). These estimates identify a small, but nevertheless, statistically significant effect from money growth and the *diseq* variable (but an insignificant effect from the output gap). The estimated model fails the linearity and parameter stability tests. As can be seen in column (iv) of Table 3, the regime-switching models in (4)-(5) deliver an estimate of δ^{m4}=9.65% for the threshold parameter and again, very small estimates for the money growth and *diseq* parameters in both "low" and "high" money growth regimes. In constrast to the estimates using *CPI* inflation, *RPIX* estimates suggest that inflation persistence is higher in the "high" money growth regime (possibly because the corresponding *M*4 money growth effect is insignificant).

Detrending output by a linear trend or a Hodrick-Prescott (1997) filter did not make any difference to the empirical results (these are available on request). The time-varying relationship between inflation and *M*4 could be pursued even further by combining models (4)-(5) and (6)-(7) in a four-regime model to allow for (i) a regime of "low" money growth and negative money disequilibrium deviations (with probability $\theta_{t-1}\phi_{t-4}$), (ii) a regime of "low" money growth and positive money disequilibrium deviations (with probability $\theta_{t-1}(1-\phi_{t-4})$), (iii) a regime of "high" money growth and negative money disequilibrium deviations (with probability $(1-\theta_{t-1})\phi_{t-4}$), and (iv) a regime of "high" money growth and positive money disequilibrium deviations (with probability $(1-\theta_{t-1})(1-\phi_{t-4})$). Such a model would be extremely demanding in the number of parameters to be estimated. Given also the earlier evidence that models (6)-(7) were only marginally better than the linear model (3), we did not pursue the four-regime model in the current paper.

4. Conclusions

Using UK data since the introduction of inflation targeting in October 1992, this paper shows that the relationship between *CPI* inflation and annual *M*4 growth is not stable over time. Following from this, and in order to address the issue of whether high *M*4 growth rates are inflationary, we adopt a regime-switching model and show that money growth movements are inflationary only when annual *M*4 growth exceeds 10%. In this "high" money growth regime, a 1 percentage point increase in the annual growth of *M*4 can only generate a 0.09 percentage points increase in UK inflation, at the same time when a 1 percentage point increase of money above equilibrium increases inflation by only 0.07 percentage points in the short run. Considering also that, in the "high" money growth regime, a 1 percentage point increase in the output gap increases inflation by five times as much as a 1 percentage point increase in either annual *M*4 growth, or money deviations from equilibrium, we conclude that the money effects are too small to justify worries that recent *M*4 movements (which are indeed above the 1992-2007 average of 8%) are highly inflationary. The implication is that the MPC do not need to be particularly worried about *M*4 movements when setting interest rate policy.

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Appendix: Non-linearity tests

Hamilton's (2001) λ-test and the λ_A and g-tests proposed by Dahl and González-Rivera (2003) assume that the conditional mean function of the dependent variable is stochastic and therefore unobservable or unknown to the econometrician. The testing procedure is based on the regression

(A.1) $y_t = \beta_0 + \boldsymbol{x}'_t \boldsymbol{\beta}_1 + \lambda m(\boldsymbol{g} \otimes \boldsymbol{x_t}) +$ error

In (A.1), the conditional mean of the dependent variable is a function of a linear and a non-linear component. The linear component is given by $\boldsymbol{x}'_t \boldsymbol{\beta}_1$ where $\boldsymbol{x_t}$ is a k-dimensional vector of the explanatory variables (excluding the intercept term). The non-linear component is given by $\lambda m(\boldsymbol{g} \otimes \boldsymbol{x_t})$, where $m(\mathbf{.})$ is a k-dimensional system of random variables depending on the distance amongst the elements of the $\boldsymbol{x_t}$ vector, and $\otimes$ denotes element-by-element multiplication. The scalar λ proxies the contribution of the non-linear part to the conditional mean, whereas $\boldsymbol{g}$ is a k-dimensional vector capturing the curvature of the conditional mean. The null hypothesis of linearity involves testing the null hypothesis H_0: $\lambda^2 = 0$ for the λ and λ_A tests and the null hypothesis H_0: $\boldsymbol{g} = \mathbf{0}_k$ for the g-test. These are Lagrange Multiplier test statistics following the χ^2 distribution (for more technical details see Hamilton, 2001, and Dahl and González-Rivera, 2003). Dahl and González-Rivera (2003) report simulation evidence according to which (i) their tests are more powerful than Hamilton's original test when the dimensionality of the model (in terms of parameters to be estimated) increases, and (ii) their tests are powerful in detecting smooth transition specifications. The latter is important as the regime-switching models we consider in this paper are smooth transition-type models.

Table 1: M4, CPI, output gap and diseq descriptive statistics

	M4 annual growth (%)	CPI inflation rate (%)	Output gap (%)	diseq (%)
Average value	8.00 (1992q4-2007q1) 12.32 (2005q1-2007q1)	1.80 (1992q4-2007q1) 2.27 (2005q1-2007q1)	-0.03 (1992q4-2007q1) -0.03 (2005q1-2007q1)	-0.85 (1992q4-2007q1) 6.64 (2005q1-2007q1)
Correlation between CPI and M4	0.20 (1992q4-2007q1) 0.51 (2005q1-2007q1)			
Correlation between CPI and output gap	-0.37 (1992q4-2007q1) 0.50 (2005q1-2007q1)			
Correlation between CPI and diseq	0.55 (1992q4-2007q1) 0.77 (2005q1-2007q1)			

Table 2: Parameter estimates, 1992q4-2007q1

	(i)	(ii)	(iii)
β_0	0.16 (0.16)	0.02 (0.23)	0.34 (0.20)
β_p	0.77 (0.06)		
β_{gap}	0.14 (0.05)		
β_{m4}	0.03 (0.01)		
β_{diseq}	0.03 (0.01)		
β_p^{Low}		0.77 (0.08)	0.77 (0.07)
β_{gap}^{Low}		0.16 (0.06)	0.32 (0.09)
β_{m4}^{Low}		0.05 (0.02)	0.03 (0.01)
β_{diseq}^{Low}		0.05 (0.02)	0.09 (0.02)
β_p^{High}		0.58 (0.18)	0.62 (0.11)
β_{gap}^{High}		0.49 (0.20)	0.04 (0.06)
β_{m4}^{High}		0.09 (0.03)	0.03 (0.01)
β_{diseq}^{High}		0.07 (0.02)	0.07 (0.04)
δ^{m4}		9.95 (0.02)	
γ^{m4}		20.10 (8.43)	
δ^{diseq}			0.01 (0.03)
γ^{diseq}			15.01 (6.63)
Adjusted R^2	0.80	0.82	0.80
Regression standard error	0.27	0.23	0.26
AR(4) (p-value)	0.57	0.58	0.59
Het (p-value)	0.34	0.36	0.37
Normality (p-value)	0.51	0.54	0.52
Parameter stability (p-value)	0.00	0.12	0.11
λ-test (p-value)	0.02		
λ_A-test (p-value)	0.01		
g-test (p-value)	0.00		

Notes: Numbers in parentheses are standard errors. Column (i) reports the parameter estimates of (3) whereas column (ii) reports the parameter estimates of (4)-(5) and column (iii) reports the parameter estimates of (6)-(7) in the main text. AR(4) is the Breusch-Godfrey 4rth order serial correlation F-test. Het is the Breusch-Pagan-Godfrey F-test for heteroskedasticity. Normality is the Jarque-Bera Chi-square test for normality. Parameter stability is an F test of parameter stability (see Lin and Teräsvirta, 1994). The table also reports bootstrapped *p*-values of the λ, λ_A, and g tests based on 1000 re-samples.

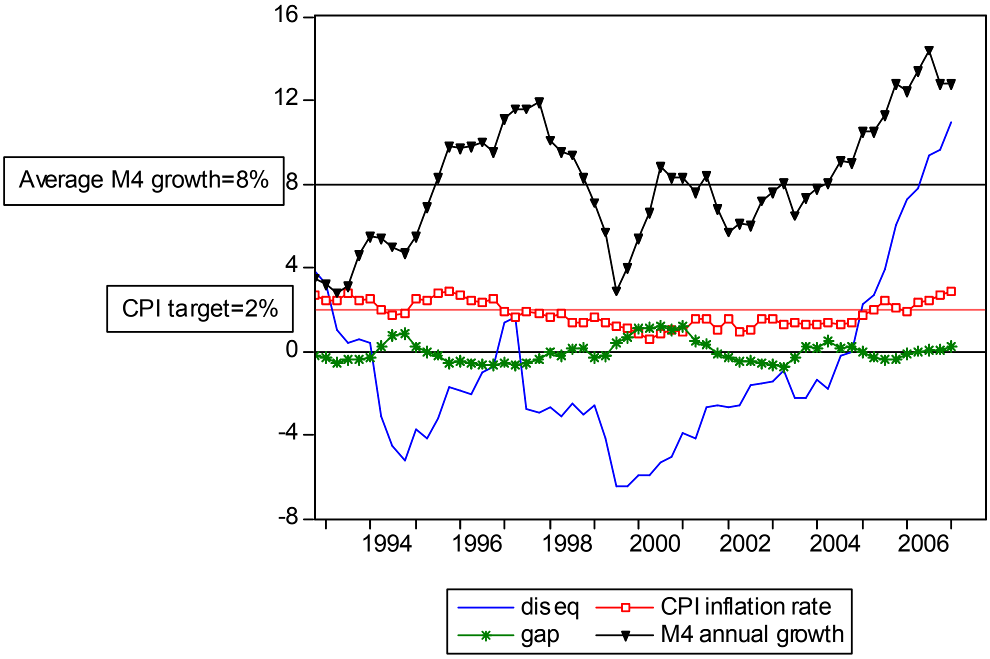
Table 3: Estimates based on alternative specifications and measures

	(i) Model with $\Delta_4 E_t p_{t+1}$	(ii) "Hybrid" model (model with $\Delta_4 p_{t-1}$ and $\Delta_4 E_t p_{t+1}$)	(iii) Model with RPIX	(iv) Models (4)-(5) with RPIX
β_0	0.37 (0.17)	0.10 (0.14)	0.65 (0.27)	0.57 (0.20)
β_p	0.82 (0.08)	0.48 (0.07)*	0.63 (0.08)	
β_{gap}	-0.03 (0.06)	0.04 (0.07)	0.03 (0.05)	
β_{m4}	-0.01 (0.01)	0.01 (0.02)	0.02 (0.01)	
β_{diseq}	0.02 (0.02)	0.01 (0.01)	0.03 (0.01)	
β_p^{Low}				0.69 (0.06)
β_{gap}^{Low}				0.04 (0.05)
β_{m4}^{Low}				0.04 (0.01)
β_{diseq}^{Low}				0.05 (0.02)
β_p^{High}				0.88 (0.06)
β_{gap}^{High}				0.29 (0.10)
β_{m4}^{High}				-0.01 (0.02)
β_{diseq}^{High}				0.05 (0.02)
δ^{m4}				9.65 (0.04)
γ^{m4}				17.03 (7.98)
δ^{diseq}				
γ^{diseq}				
Parameter stability (p-value)	0.06	0.05	0.03	0.12
λ-test (p-value)	0.12	0.11	0.02	
λ_A-test (p-value)	0.11	0.06	0.01	
g-test (p-value)	0.09	0.08	0.01	

Notes: Numbers in parentheses are standard errors.

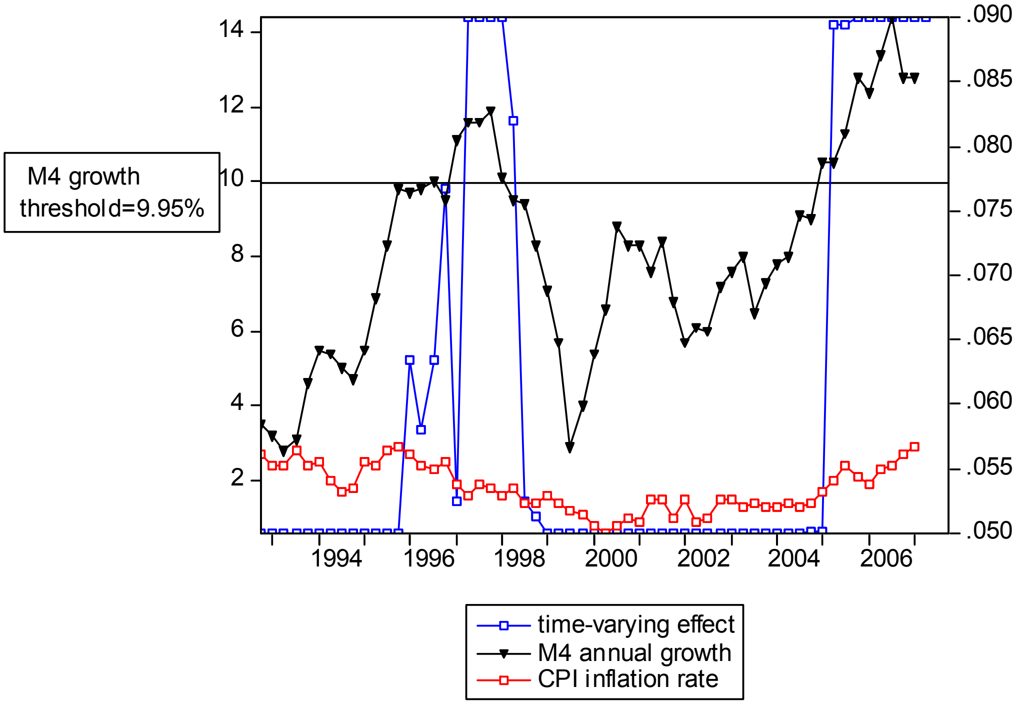
* Restricted coefficient estimate on $\Delta_4 p_{t-1}$. The unrestricted estimates are: 0.43 (standard error=0.07) for $\Delta_4 p_{t-1}$ and 0.50 (standard error=0.08) for $E_t \Delta_4 p_{t+1}$. The *p*-value that these weights sum up to one is equal to 0.32. Parameter stability is an F test of parameter stability (see Lin and Teräsvirta, 1994). The table also reports bootstrapped *p*-values of the λ, λ_A, and *g* tests based on 1000 re-samples.

Figure 1: UK data, 1992q4-2007q1



Note: *CPI* inflation rate, 2% target, output gap, diseq, *M*4 growth and 8% average rate.

Figure 2: The time-varying effect of M4 growth on CPI inflation



Note: The time-varying effect is equal to $\theta_{t-1}\beta_{m4}^{Low} + (1-\theta_{t-1})\beta_{m4}^{High}$, using β_{m4}^{Low}=0.05 and β_{m4}^{High}=0.09 (see the estimates in column (ii) of Table 2).

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