

Bauer, Christian; Neuenkirch, Matthias

Working Paper

Forecast uncertainty and the Taylor rule

Research Papers in Economics, No. 5/15

Provided in Cooperation with:

University of Trier, Department of Economics

Suggested Citation: Bauer, Christian; Neuenkirch, Matthias (2015) : Forecast uncertainty and the Taylor rule, Research Papers in Economics, No. 5/15, Universität Trier, Fachbereich IV – Volkswirtschaftslehre, Trier

This Version is available at:

<https://hdl.handle.net/10419/111759>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.

Forecast Uncertainty
and the Taylor Rule

Christian Bauer
Matthias Neuenkirch



Research Papers in Economics
No. 5/15

Forecast Uncertainty and the Taylor Rule*

Christian Bauer[†]

Matthias Neuenkirch[‡]

University of Trier, Germany

University of Trier, Germany

April 21, 2015

Abstract

In this paper, we derive a modification of a forward-looking Taylor rule, which integrates two variables measuring the uncertainty of inflation and GDP growth forecasts into an otherwise standard New Keynesian model. We show that certainty-equivalence in New Keynesian models is a consequence of log-linearization and that a second-order Taylor approximation leads to a reaction function which includes the uncertainty of macroeconomic expectations. To test the model empirically, we use the standard deviation of individual forecasts around the median Consensus Forecast as proxy for forecast uncertainty. Our sample covers the euro area, Sweden, and the United Kingdom and the period 1992Q4–2014Q2. We find that while all three central banks react significantly to inflation forecast uncertainty by reducing their policy rates in times of higher inflation expectation uncertainty with an average effect of more than 25 basis points, they do not have significant reactions to GDP growth forecast uncertainty. We conclude with some implications for optimal monetary policy rules and central bank watchers.

JEL Codes: E52, E58.

Keywords: Certainty-Equivalence, Consensus Forecasts, Forecast Uncertainty, Global Financial Crisis, Optimal Monetary Policy, Taylor Rule.

*We thank Peter Tillmann for his helpful comments on an earlier version of the paper. The usual disclaimer applies.

[†]Email: bauer@uni-trier.de.

[‡]Email: neuenkirch@uni-trier.de.

1 Introduction

The former Chairman of the Federal Reserve (Fed), Alan Greenspan, when writing about his inside view on how monetary policy is instituted, states that the Fed is well aware of the effects of uncertainty on macroeconomic variables (Greenspan 2004). Such uncertainties may stem from two sources. On the one hand, future values of macroeconomic variables are part of the central bank’s policy objectives and their expectations influence current values. On the other hand, there are unobservable variables and problems with measuring the relevant variables in real-time.

The relevance of macroeconomic uncertainty for rule formation of central banks has been extensively discussed in the theoretical literature. Swanson (2004) states that “a standard result in the literature of monetary policy is that of certainty-equivalence: Given the expected value of the state variables of the economy, policy should be independent of the higher moments of those variables.” This view is based on a series of seminal papers. Orphanides (2003) shows that certainty-equivalence holds for models with unobserved or real-time data and emphasizes that the independence of the parameters holds only if the optimal rule is based on the expected values of the macroeconomic variables rather than their measured values. Svensson and Woodford (2003) find that “the optimal response to the optimal estimate of potential output displays certainty equivalence, whereas the optimal response to the imperfect observation of output depends on the noise in this observation.” These and all subsequent papers on certainty-equivalence deal with more or less complex but *linear* models of the economy, which is another shortcoming in the view of central bankers. Greenspan (2004) also states that in making their decisions the Fed takes into account the insufficiencies of the commonly used linear macroeconomic models. Nevertheless, to this point in time, the certainty-equivalence principle holds—to the best of our knowledge—for all derivations of monetary policy rules in linear New Keynesian models (NKM) (see also the textbooks by Gali 2008 and Walsh 2010).

So far, few alternatives have been analyzed as, for instance, Swanson (2004) shows that an exception from the result of certainty-equivalence is possible only if the policy rule is expressed in reduced form and relevant unobserved variables are estimated in a signal extraction sense. Consequently, the paper’s first contribution is to close the gap between academic theory and the de facto behavior of central bankers. We show that certainty-equivalence in NKM holds if and only if the model is solved by log-linearization. The basic intuition is quite simple. Log-linearizing the variables within the expectation operator eliminates higher order moments. In con-

trast, using a second-order Taylor approximation preserves the second moments and the variance remains relevant for the optimal policy rule. Accordingly, we present a modification of a forward-looking Taylor rule, which integrates two variables measuring the *uncertainty* of inflation and GDP growth *forecasts* into an otherwise standard NKM. This result is generic to NKM and not specific to our (standard) setup. One implication is that Taylor-type optimal policy rules should not ignore the uncertainty of macroeconomic variables when taking the cautious behavior of central bankers seriously.

There has also been little research into the question of how central banks empirically deal with the uncertainty of macroeconomic forecasts in their reaction function. Extant papers on the Taylor (1993) rule and its modifications (see among many others, Clarida et al 1998 and Orphanides 2001) have focused on the point estimates of macroeconomic forecasts and ignored the uncertainty of these forecasts. To the best of our knowledge, there are only two exceptions. Branch (2014) augments a Taylor rule for the US with indicators of uncertainty obtained from the *Survey of Professional Forecasters*. He finds that the Fed negatively responded to both uncertainty in the inflation nowcast and uncertainty to the output gap nowcast during the period 1993Q1–2008Q3. In addition, Milas and Martin (2009) assume noise dependent coefficients for a rule based on expected values and find that the Fed responded less vigorously to inflation and the output gap when these variables are observed with less certainty during the period 1983Q1–2003Q4.

Another branch of the empirical Taylor rule literature, which is closely related to this paper includes work by Nobay and Peel (2003). If central bankers have an asymmetric loss function this might translate into a reaction function with larger parameters for negative (positive) deviations of inflation or output from target compared to positive (negative) ones or into state-dependent parameters for contractions and expansions.¹ Such an asymmetric loss function might also be relevant in the context of macroeconomic forecasts. As mentioned before, monetary policy is supposed to be forward-looking. Consequently, policymakers have to deal with more or less certain forecasts when they determine the appropriate level of the policy rate. They have to decide whether to weigh the upward and downward risks of a forecast as balanced, or to give one of these risks more weight in formulating their decision. For instance, a high degree of inflation forecast uncertainty and a relatively stronger aversion of overshooting the inflation target (IT) should translate into a positive re-

¹Empirical contributions include, among others, Ruge-Murcia (2003), Surico (2007a), and Surico (2007b).

action to the uncertainty of inflation expectations. Similarly, when the central bank is more recession-averse and observes a high degree of GDP forecast uncertainty it should lower its policy rate. Consequently, there are possible scenarios when a central bank should react to the second moment of inflation or growth expectations forecasts from this point of view as well.²

Given the scant empirical literature on how central bankers deal with the uncertainty of macroeconomic forecasts, the paper's second contribution is to test a forward-looking Taylor rule with inflation forecast uncertainty and GDP growth forecast uncertainty empirically. For that purpose, we rely on the dataset of individual forecasters provided by *Consensus Economics* and use the standard deviation of individual forecasts around the median forecast as proxy for forecast uncertainty.³ Our sample covers three economies (euro area, Sweden, and the United Kingdom) and the period 1992Q4–2014Q2, which allows us to compare not only the reaction to uncertainty of several central banks, but also to look at their forecast error risk aversion during normal times and during the episode of the global financial crisis and thereafter.

Our results indicate that, in fact, real policy behavior accounts for uncertainty in accordance with the model's predictions. All three central banks significantly react to inflation forecast uncertainty but not to GDP growth forecast uncertainty. They reduce their policy rates in times of higher inflation expectation uncertainty with an average effect of more than 25 basis points. The inclusion of the second moments of forecasts leads to a slightly better model fit, lower standard errors of regression, and an improvement of the information criteria in the regressions.

The remainder of this paper is as follow. Section 2 presents the modified New Keynesian model. Section 3 introduces the data set and the empirical methodology. Section 4 shows the empirical results. Section 5 concludes.

2 Theoretical Model

In this section, we present a modification of an otherwise standard NKM, which results in a monetary policy reaction function that also includes the second moments

²In addition, an asymmetric loss function can be relevant in the forecast-generating process as well. See, for instance, Patton and Timmermann (2007) and Capistran (2008). If central bankers fear under-predicting inflation they will adjust their forecast of inflation up by a factor that is increasing in forecast uncertainty.

³These forecasts are a reasonable proxy for central bank forecasts as professional forecasters have very similar backgrounds to staff economists at central banks.

of inflation expectations and GDP growth expectations.⁴ The model setup follows Gali (2008). The only difference to the standard setup is that we relax the solution method of log-linearization and use a second-order approximation.

2.1 The New Keynesian Phillips Curve

Consumer, Prices, and Aggregation. We start with a standard monopolistic Dixit-Stiglitz type competition model. Firms have pricing power on a continuum of differentiated goods indexed by $i \in [0, 1]$. We assume that the elasticity of substitution between goods $\varepsilon > 1$ is constant and common amongst all economic subjects. $C(i)$ denotes the consumption level and $P(i)$ is the price of good i .⁵ Consequently, the total expenditure on consumption is $\int_0^1 P(i)C(i)di$ and the composite consumption index C is

$$C = \left(\int_0^1 C(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}}. \quad (1)$$

The representative consumer minimizes the expenditure for C units of aggregate consumption yielding the following Lagrangian

$$L = \int_0^1 P(i)C(i)di - \lambda \left(\left(\int_0^1 C(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}} - C \right). \quad (2)$$

Using the first-order conditions

$$P(i) = \lambda C(i)^{-\frac{1}{\varepsilon}} \left(\int_0^1 C(j)^{\frac{\varepsilon-1}{\varepsilon}} dj \right)^{\frac{1}{\varepsilon-1}} \quad (3)$$

results in

$$\frac{C(i)}{C} = \left(\frac{P(i)}{P} \right)^{-\varepsilon}, \quad (4)$$

which—after taking the $\frac{\varepsilon}{\varepsilon-1}$ th root and integration with respect to i —yields the price index

⁴Other approaches to introduce uncertainty variables into a monetary policy rule like, for instance, Swanson (2004) are based on an signaling approach and yield uncertainty dependent coefficients for inflation and output instead of separable coefficients for inflation and output uncertainty as our approach does.

⁵To keep the notation as simple as possible we omit the time index as long as we treat only a single period.

$$P = \left(\int_0^1 P(i)^{1-\varepsilon} di \right)^{\frac{1}{1-\varepsilon}}. \quad (5)$$

The Firms' Problem. K denotes the firms' cost functions in real terms of quantities $Y(i)$ and $Z(i) \equiv K'(Y(i))$ the marginal costs. We assume that the log deviations of marginal costs from their long-run trend values $z(i)$ are linear, that is,

$$z(i) \equiv \ln Z(i) = \gamma y(i).$$

The firm's real profits are given by

$$\Pi(i) = \frac{P(i)Y(i)}{P} - K(Y(i)). \quad (6)$$

Each firm takes the demand function and aggregate prices as given since any single firm is too small to directly influence other firms or the whole economy. It sets its own price $P(i)$ to maximize profits. Standard optimization yields a fixed mark-up over marginal costs:⁶

$$\frac{P(i)^*}{P} = \left(\frac{\varepsilon}{\varepsilon - 1} \right) K' \left(\frac{P(i)^{-\varepsilon}}{P} Y \right) = \left(\frac{\varepsilon}{\varepsilon - 1} \right) K'(Y(i)). \quad (7)$$

We denote the log deviation of individual prices and the price index from their long-term values by $p \equiv \ln P - \ln \bar{P}$ and $p(i) \equiv \ln P(i) - \ln \bar{P}$. Taking logs and substituting the demand function in logs $y(i) - y = -\varepsilon(p(i) - p)$ yields

$$p(i)^* - p = \left(\frac{\gamma}{1 + \varepsilon\gamma} \right) y = \alpha \hat{y} \quad (8)$$

with $\alpha \equiv \left(\frac{\gamma}{1 + \varepsilon\gamma} \right) \in [0, 1]$.

Price Rigidity: Calvo Pricing. Each firm has a constant probability $1 - \phi$ to be able to update its price in each period and the turns are independently distributed among firms and periods. This implies a probability of ϕ^j for having the same price in j periods as today. We denote the reset price as $x_t = p_t(i)$. This is not necessarily the optimal price p_t^* , because firms will act on the probability of not to being able to adjust prices in future periods. Indeed, the optimal reset price is determined

⁶Note that the steady state log marginal costs is equal to negative markup in logs: $z_{ss} = -\ln\left(\frac{\varepsilon}{\varepsilon-1}\right)$.

by the discounted sum of future profits. We use a quadratic approximation of the per-period deviation from maximum-possible profit with β as discount factor

$$-\frac{c}{2} \sum_{j=0}^{\infty} \beta^j \phi^j E_t \left[(x_t - p_{t+j}^*)^2 \right]. \quad (9)$$

The first-order condition is

$$\begin{aligned} x_t &= (1 - \beta\phi) \sum_{j=0}^{\infty} (\beta\phi)^j E_t [p_{t+j}^*] \\ &= \beta\phi E_t [x_{t+1}] + (1 - \beta\phi) p_t^*. \end{aligned} \quad (10)$$

We know from its definition and the definition of the price updating probability ϕ that the aggregate price level evolves according to

$$p_t = \phi p_{t-1} + (1 - \phi) x_t. \quad (11)$$

Using (10) to substitute for x_t yields

$$p_t - \phi p_{t-1} = (1 - \phi) (\beta\phi E_t [x_{t+1}] + (1 - \beta\phi) p_t^*). \quad (12)$$

(12) can further be simplified by defining inflation as $\pi_t \equiv p_t - p_{t-1}$ to

$$\pi_t = \beta E_t [\pi_{t+1}] + \left(\frac{(1 - \phi)(1 - \beta\phi)}{\phi} \right) (p_t^* - p_t). \quad (13)$$

Recalling the optimal price equation (8) and defining $\kappa \equiv \frac{\alpha(1-\phi)(1-\beta\phi)}{\phi}$ yields the New Keynesian Phillips curve (NKPC)

$$\pi_t = \beta E_t [\pi_{t+1}] + \kappa \hat{y}_t. \quad (14)$$

2.2 The Quadratic IS curve

Households maximize their discounted expected utility $E_t \sum_{s=t}^{\infty} \beta^{t-s} U(C_s)$ under a dynamic budget constraint with the interest rate i_t . This leads to the Euler equation⁷

$$\frac{U'(C_t)}{P_t} = \beta (1 + i_t) E_t \left(\frac{U'(C_{t+1})}{P_{t+1}} \right).$$

⁷The utility function could incorporate other factors as money or working hours in a standard way which would not influence our analysis since we rely only on the Euler equation.

Consumption enters the utility as $C_t^{1-\sigma}$ with an elasticity of intertemporal substitution of $1/\sigma$ which yields

$$\frac{1}{\beta(1+i_t)} = E_t \left(\frac{P_t}{P_{t+1}} \left(\frac{Y_{t+1}}{Y_t} \right)^{-\sigma} \right). \quad (15)$$

We define the growth rate $\Delta y_{t+1} = \ln Y_{t+1} - \ln Y_t$ and the output gap $\widehat{y}_t = y_t - y_{ss}$.⁸ It is consistent with the long-run equilibrium to choose $\beta = \frac{1}{1+r}$ with r being the real interest rate which results in

$$\frac{1+r}{1+i_t} = E_t (\exp(-\pi_{t+1} - \sigma \Delta \widehat{y}_{t+1})). \quad (16)$$

We now deviate from the standard derivation of the IS curve and use a quadratic approximation $\exp(x) \approx 1 + x + \frac{1}{2}x^2$ and take the log-lins of the interest rate⁹

$$1+r-i_t \approx E_t \left(1 - \pi_{t+1} - \sigma \Delta \widehat{y}_{t+1} + \frac{1}{2} (\pi_{t+1} + \sigma (\Delta \widehat{y}_{t+1}))^2 \right). \quad (17)$$

Solving for the output gap yields the quadratic IS curve

$$\widehat{y}_t = E_t (\widehat{y}_{t+1}) - \frac{1}{\sigma} (i_t - r - E_t \pi_{t+1}) - \frac{1}{2\sigma} E_t \pi_{t+1}^2 - \frac{\sigma}{2} E_t (\Delta \widehat{y}_{t+1})^2 - E_t (\pi_{t+1} \Delta \widehat{y}_{t+1}). \quad (18)$$

The derivations of the NKPC and the IS curve are both microfounded and follow the lines of the standard approaches. In both cases (Equations (9) and (17)), we use a second order approximation. However, variance parameters only enter the IS curve. In the derivation of the IS curve, we approximate the Euler equation, which includes non- t -measurable variables, that is, the future price level and future output. Consequently, higher order moments of these variables remain after the second order approximation. In the derivation of the NKPC, we approximate the objective function around the t -measurable optimizing variable x_t in the expectation operator. Consequently, the first-order conditions are linear in x_t and also in the

⁸It is straightforward to show that the growth rate of the output and the growth rate of the output gap is the same: $\Delta y_{t+1} = y_{t+1} - y_{ss} - (y_t - y_{ss}) = \Delta \widehat{y}_{t+1}$.

⁹This step is the crucial difference to the standard derivation of the IS curve. If we apply a log-linearization, the term $\frac{1}{2}x^2$ would be left out. In this case, the term within the expectation operator would be linear and we were left with separated terms of expected inflation and the expected output gap, that is, the standard derivation of the IS curve. Note that, however, the inclusion of moments higher than second order would make the model intractable.

log price level.¹⁰ Thus, the main difference is that the approximated variable is t -measurable in case of the NKPC but not in case of the IS curve.

2.3 Monetary Policy under Discretion

The central bank minimizes squared fluctuations of inflation around a constant target π^* being set to zero for convenience and squared fluctuations of the output gap weighted by $\delta > 0$

$$\mathcal{L} = \frac{1}{2}\pi_t^2 + \frac{\delta}{2}\widehat{y}_t^2 \quad (19)$$

by choosing its policy rate i_t^T . The central bank is assumed to be unable to commit to the fully optimal, that is, inertial, policy plan. Instead, monetary policy operates under discretion and takes expectations of future inflation and future output as given.

Recall the NKPC (14) and the quadratic IS curve (18)

$$\begin{aligned} \pi_t &= \beta E_t \pi_{t+1} + \kappa \widehat{y}_t \\ \widehat{y}_t &= E_t(\widehat{y}_{t+1}) - \frac{1}{\sigma}(i_t - r - E_t \pi_{t+1}) - \frac{1}{2\sigma} E_t \pi_{t+1}^2 - \frac{\sigma}{2} E_t (\Delta \widehat{y}_{t+1})^2 - E_t(\pi_{t+1} \Delta \widehat{y}_{t+1}), \end{aligned}$$

where the parameters β , κ , and σ are strictly positive. Minimizing equation (19) with respect to inflation and the output gap, subject to the NKPC and the quadratic IS curve, results in two first-order conditions $\lambda = -\pi_t$ and $\lambda = \frac{\delta}{\kappa} \widehat{y}_t$ that can be combined to the standard targeting rule

$$\pi_t = -\frac{\delta}{\kappa} \widehat{y}_t. \quad (20)$$

According to this rule, the central bank “leans against the wind” and depresses the real economy to counteract positive deviations from the inflation target. The strength of the economic contraction needed to fight an inflation deviation increases in the slope of the NKPC and decreases in the central bank’s weight on output stabilization. Inserting the standard targeting rule (20) into the NKPC yields:

$$\widehat{y}_t = -\frac{\beta \kappa}{\delta + \kappa^2} E_t \pi_{t+1} \quad (21)$$

¹⁰Note that a derivation of the NKPC without a second-order approximation also leads to a partial solution without higher moments which, however, is not fully solvable any more.

To obtain the interest rate rule followed by the central bank we insert (21) into the quadratic IS curve and solve for the central bank's policy rate:¹¹

$$\begin{aligned}
i_t^T &= r + \left(1 + \frac{\sigma\kappa\beta}{\delta + \kappa^2}\right) E_t\pi_{t+1} + \sigma E_t(\widehat{y}_{t+1}) \\
&+ \left(\frac{\sigma\kappa}{\delta} - \frac{1}{2}\right) Var(\pi_{t+1}) - \frac{\sigma^2}{2} Var(\widehat{y}_{t+1}) \\
&+ \left(\frac{\sigma\kappa}{\delta} - \frac{1}{2} - \frac{\sigma\beta\kappa}{\delta + \kappa^2}\right) (E_t\pi_{t+1})^2 - \frac{\sigma^2}{2} (E_t\widehat{y}_{t+1} - \widehat{y}_t)^2 \quad (22)
\end{aligned}$$

Finally, we utilize the “lean against the wind” condition to clarify the relation between the coefficients and get as a target interest rate

$$i_t^T = r + \lambda_1 E_t(\pi_{t+1}) + \lambda_2 E_t(\widehat{y}_{t+1}) + \lambda_3 Var_t(\pi_{t+1}) + \lambda_4 Var(\widehat{y}_{t+1}) + \xi \quad (23)$$

with

$$\begin{aligned}
\lambda_1 - \frac{\delta}{\kappa}\lambda_2 &= \sigma - \frac{\delta}{\kappa} \left(1 + \frac{\sigma\beta\kappa}{\delta + \kappa^2}\right) \\
\lambda_3 + \left(\frac{\delta}{\kappa}\right)^2 \lambda_4 &= -\frac{\sigma^2}{2} - \left(\frac{\delta}{\kappa}\right)^2 \left(\frac{\sigma\kappa}{\delta} - \frac{1}{2}\right) \\
\xi &= \left(\frac{\sigma\kappa}{\delta} - \frac{1}{2} - \frac{\sigma\beta\kappa}{\delta + \kappa^2}\right) (E_t\pi_{t+1})^2 - \frac{\sigma^2}{2} (E_t\widehat{y}_{t+1} - \widehat{y}_t)^2.
\end{aligned}$$

The term ξ can be neglected as the squared expected inflation rate¹² and the squared expected output gap growth rate take very small values for advanced economies.

3 Data and Empirical Methodology

3.1 Data

Our empirical analysis focuses on three mature economies: the euro area (EA), Sweden (SWE), and the United Kingdom (UK). The sample countries and the period covered for each central bank is summarized in Table 1.

¹¹Thereby, we use $Var(x) = E(x^2) - (Ex)^2$.

¹²Note that this term corresponds to the squared expected deviation of the inflation rate from its target, the latter of which is assumed to be zero.

Table 1: Sample Countries

Country	“IT” since	Start Date	End Date
Euro Area	1999Q1	2002Q4	2014Q2
Sweden	1993Q1	1995Q1	2014Q2
United Kingdom	1992Q4	1992Q4	2009Q2

In case of the euro area, the sample starting date is 2002Q4 as individual forecasts by *Consensus Economics* for the entire EA first became available in December 2002.¹³ Similarly, the sample start for Sweden is 1995Q1 (two years after the inception of the Riksbanks inflation target of 2%) as individual forecasts by *Consensus Economics* became available in January 1995. Finally, conventional monetary policy has become less relevant in the UK at the zero-lower bound of interest rates. In fact, we do not observe a single change in the Bank of England’s policy rate after March 2009. Consequently, we restrict the end of the sample period to the quarter after the last policy rate change.

Our data set includes the end of quarter policy rates obtained from the central bank websites. In addition, for each country there are up to 34 individual forecasts by *Consensus Economics* for expected inflation and real GDP growth, separately for the *current calendar year* and the *next calendar year*. In a first step, these individual forecasts are transformed into *12-month ahead* forecasts using the following formula.

$$E_{t,i}x_{t+12} = \frac{12-m}{12}E_{t,m,i}x_{cy} + \frac{m}{12}E_{t,m,i}x_{ny} \quad (24)$$

$E_{t,i}x_{t+12}$ is the 12-month ahead forecast and $E_{t,m,i}x_{cy}$ as well as $E_{t,m,i}x_{ny}$ are the corresponding forecasts for the current calendar year and the next calendar year. i denotes the individual forecaster and m refers to the month in which the forecast was made, that is, $m = 3$ for March, $m = 6$ for June, $m = 9$ for September and, $m = 12$ for December. In a second step, we calculate the median of these individual forecasts for each country and month. In the following, we will refer to these medians as “expected inflation” and “expected GDP growth.” Finally, we obtain the standard deviation around the median for each country and forecast to proxy the “uncertainty of inflation expectations” and “uncertainty of growth expectations.” In contrast to the theoretical model in Section 2, we use the standard deviation around the median

¹³Note that it is common practice to use real-time national GDP weights to aggregate national inflation forecasts and growth forecasts as a proxy for the euro area forecasts before December 2002. Such an approach—which is well-suited for the level of forecasts—does perform poorly for the second moment of forecasts as indicated by a comparison of the actual uncertainty of euro area forecasts and this proxy measure for the period after December 2002.

instead of the variance as the standard deviation has the same dimension as the median and, therefore, these figures are easier to interpret.¹⁴

Figures A1–A3 in the Appendix show the policy rates, inflation and GDP growth expectations, and the uncertainty of expectations over time. Table A1 presents the corresponding descriptive statistics. A couple of things are worth highlighting. First, the uncertainty of inflation expectations is lower than the uncertainty of growth expectations in all three economies. Second, the uncertainty of inflation expectations is less volatile than the uncertainty of growth expectations in the EA and SWE, whereas we observe the opposite in the UK. Third, the uncertainty of growth expectations increases after 2007 in the EA and SWE and decreases towards the end of the sample period.

Table A2 provides further interesting insights by showing bivariate correlations between the five variables. First, there is a positive correlation between both forecast uncertainty measures in all three economies. The strongest positive correlation is found for the EA (0.67), the weakest for the UK (0.15). Second, in times of higher expected growth both, inflation and GDP forecast uncertainty is generally lower. Third, there is a positive correlation between inflation forecast uncertainty and the expected level of inflation in the UK (cf., Friedman 1977; Cukierman and Meltzer 1986; Ball 1992), whereas we observe the opposite for the EA (cf., Pourgerami and Maskus 1987; Ungar and Zilberfarb 1993). Finally, output forecast uncertainty is lower in times of higher inflation expectations in the euro area.

3.2 Empirical Methodology

To assess the impact of inflation and GDP growth forecast uncertainty on the central bank policy rate we, first, estimate a forward-looking Taylor rule without forecast uncertainty as a benchmark. To reconcile our theoretical model in Section 2 with the recent empirical literature (Coibion and Gorodnichenko 2012), we allow for both, interest rate smoothing of second-order and a first-order autoregressive error term specification.¹⁵

¹⁴Note that the results below hold qualitatively when using the variance around the median instead of the standard deviation. See Table A3 in the Appendix.

¹⁵See also Rudebusch (2006) and Consolo and Favero (2009) for a discussion of whether to include a partial adjustment mechanism and/or an autoregressive error term into the reaction function.

$$\begin{aligned}
i_t^T &= \rho_{i,1}i_{t-1}^T + \rho_{i,2}i_{t-2}^T + \alpha + \beta_1(E_t\pi_{t+12} - \pi^*) + \beta_2(E_t y_{t+12} - y^*) + u_t \quad (\text{M1}) \\
u_t &= \rho_u u_{t-1} + e_t
\end{aligned}$$

i_t^T is the policy rate, $E_t\pi_{t+12} - \pi^*$ the 12-month ahead expected inflation rate minus the IT, that is, the “expected inflation gap,” and $E_t y_{t+12} - y^*$ the 12-month ahead expected GDP growth rate minus potential output, that is, the “expected output gap.”¹⁶ π^* takes the values of the explicit ITs in SWE and the UK and the inflation objective in case of the European Central Bank (ECB). Following the recent literature on Taylor rules (see, for instance, Gorter et al 2008; Neuenkirch and Siklos 2013; Neuenkirch and Tillmann 2014) we use a simple deviation from a constant output growth trend (2%) as proxy for the output gap.¹⁷

Finally, reflecting the findings of Orphanides (2001), we analyze monetary policy decisions in real-time which implies that the end of quarter policy rate is regressed on the respective latest available forecast, that is the March, June, September, or December forecast. Since all right-hand side variables are observables we estimate (M1) using OLS (see also Coibion and Gorodnichenko 2011).

Next, we augment (M1) with variables measuring the uncertainty of inflation forecasts and the uncertainty of GDP growth forecasts:

$$\begin{aligned}
i_t^T &= \rho_{i,1}i_{t-1}^T + \rho_{i,2}i_{t-2}^T + \alpha + \beta_1(E_t\pi_{t+12} - \pi^*) + \beta_2(E_t y_{t+12} - y^*) \quad (\text{M2}) \\
&\quad + \gamma_1 SD(E_t\pi_{t+12}) + \gamma_2 SD(E_t y_{t+12}) + u_t \\
u_t &= \rho_u u_{t-1} + e_t
\end{aligned}$$

$SD(E_t\pi_{t+12})$ is the uncertainty of inflation expectations and $SD(E_t y_{t+12})$ is the uncertainty of growth forecasts. A positive (and significant) value for γ_1 or γ_2

¹⁶We choose not to add an exchange rate variable. Research on estimated as well as optimal Taylor rules (see, among others, Clarida 2001; Collins and Siklos 2004) suggests that adding this variable does not substantively change inferences based on the standard Taylor rule specification.

¹⁷This also reflects common practice by many central banks in their communications as these focus on expected GDP growth rather than on the expected GDP gap (Gerlach 2007), probably due to the difficulty of measuring the latter in real-time (see also Orphanides and van Norden 2002). A widely followed practice in the relevant literature suggests employing the Hodrick and Prescott (1997) filter with the standard smoothing parameter $\lambda = 1600$. However, this assumes perfect knowledge of all future expected output observations since it estimates trend output based on a two-sided filter. Alternative formulations of this filter address some of the drawbacks with the standard version but these alternatives remain more ad hoc than the definitions we rely upon in the empirical work below.

implies that the central bank increases its policy rate in response to higher inflation (growth) forecast uncertainty. In such a situation, the central bank is more averse to overshooting its inflation or growth target than to undershoot it. The opposite holds for negative (and significant) values of γ_1 or γ_2 . Then, the central bank's loss function is asymmetric in a sense that an undershooting of the respective target is the bigger concern. Finally, the variables i_t^T , $E_t\pi_{t+12} - \pi^*$, and $E_t y_{t+12} - y^*$ are defined as above and (M2) is estimated using OLS.

4 Empirical Results

4.1 Euro Area

Table 2 sets out the results for the euro area. The left panel shows the results for the baseline specification (M1) and the right panel presents estimates for the augmented specification including the variables measuring forecast uncertainty (M2). The steady state coefficients are the values of $\alpha/(1 - \rho_{i,1} - \rho_{i,2})$, $\beta_1/(1 - \rho_{i,1} - \rho_{i,2})$, $\beta_2/(1 - \rho_{i,1} - \rho_{i,2})$, $\gamma_1/(1 - \rho_{i,1} - \rho_{i,2})$, and $\gamma_2/(1 - \rho_{i,1} - \rho_{i,2})$ and provide useful information about the long-run adjustment of the policy rate to the explanatory variables.

We observe a high degree of interest rate smoothing as indicated by the sum of the parameters $\rho_{i,1}$ and $\rho_{i,2}$ (0.81 in the baseline specification and 0.84 in the augmented specification). We also have evidence for persistent monetary policy shocks as the autoregressive error term is significant in both specifications as well. Roughly 55 to 57 percent of the last period's shock carries over to the current period. The so-called Taylor principle is met as a 1 percentage point (pp) increase in the expected inflation gap is associated with a raise of the nominal interest rate by more than 1 pp in both specifications (2.1 pp and 2.4 pp, respectively). In addition, the ECB also puts considerable weight on output stabilization as the coefficient is significant and even above Taylor's normative guidepost of 0.5 in both specifications (1.6 pp and 1.3 pp, respectively). Finally, the estimates of the uncertainty indicators are quite revealing. The ECB significantly reacts to inflation forecast uncertainty but not to GDP growth forecast uncertainty. The negative sign implies that ECB officials feared overshooting the inflation objective more than undershooting it.

Table 2: Taylor Rules for the Euro Area

Dependent Variable: i_t^T	EA (M1)			EA (M2)		
	Coef.	S.E.	p-val.	Coef.	S.E.	p-val.
$\rho_{i,1} : i_{t-1}^T$	0.250	(0.317)	[0.44]	0.394	(0.248)	[0.12]
$\rho_{i,2} : i_{t-2}^T$	0.559	(0.251)	[0.03]	0.445	(0.201)	[0.03]
$\rho_{i,1} + \rho_{i,2}$	0.808	(0.090)	[0.00]	0.839	(0.069)	[0.00]
$\rho_u : u_{t-1}$	0.570	(0.288)	[0.05]	0.548	(0.244)	[0.03]
α	0.649	(0.243)	[0.01]	0.963	(0.232)	[0.00]
$\beta_1 : E_t \pi_{t+12} - \pi^*$	0.402	(0.155)	[0.01]	0.388	(0.142)	[0.01]
$\beta_2 : E_t y_{t+12} - y^*$	0.308	(0.106)	[0.01]	0.206	(0.100)	[0.05]
$\gamma_1 : SD(E_t \pi_{t+12})$				-2.891	(0.822)	[0.00]
$\gamma_2 : SD(E_t y_{t+12})$				-0.048	(0.473)	[0.92]
<i>Steady State Coefficients</i>						
Constant Term	3.39	(1.27)	[0.01]	5.99	(1.44)	[0.00]
$E_t \pi_{t+12} - \pi^*$	2.10	(0.81)	[0.01]	2.41	(0.88)	[0.01]
$E_t y_{t+12} - y^*$	1.61	(0.55)	[0.01]	1.28	(0.62)	[0.05]
$SD(E_t \pi_{t+12})$				-17.97	(5.11)	[0.00]
$SD(E_t y_{t+12})$				-0.30	(2.94)	[0.92]
R^2		0.97			0.98	
σ		0.22			0.20	
AIC		-0.04			-0.24	
SC		0.20			0.08	
Breusch-Godfrey Test	$\chi^2(4) = 1.3$ [0.87]			$\chi^2(4) = 1.4$ [0.85]		
White Test	$\chi^2(6) = 24.9$ [0.00]			$\chi^2(8) = 21.1$ [0.01]		
Standard Errors	White (1980)			White (1980)		

Notes: Estimation of (M1) (left panel) and (M2) (right panel) using OLS. Number of observations: 45. Steady state coefficients are obtained by setting $i_t^T = i_{t-1}^T = i_{t-2}^T$. σ : standard error of regression; AIC: Akaike information criterion; SC: Schwarz criterion.

4.2 Sweden

Table 3 sets out the results for Sweden. The estimates of the Riksbank's interest rate smoothing parameters are similar to those for the ECB (0.81 in the baseline specification and 0.82 in the augmented specification). Persistent monetary policy shocks, however, play even a larger role in Sweden with coefficients for the autoregressive error term of 0.72 and 0.76. The Taylor principle is also met as the steady state estimates indicate a 2.8–3.1 pp increase to 1 pp change in the expected inflation gap. The estimates of the expected output gap are, again, similar to the ECB (1.6 in the baseline specification and 1.3 in the augmented specification). Finally, the Riksbank also responds to inflation forecast uncertainty. The reaction, however, is

not as profound as that of the ECB, as the coefficient on γ_1 is smaller and significant only at the ten percent level.

Table 3: Taylor Rules for Sweden

Dependent Variable: i_t^T	SWE (M1)			SWE (M2)		
	Coef.	S.E.	p-val.	Coef.	S.E.	p-val.
$\rho_{i,1} : i_{t-1}^T$	0.187	(0.253)	[0.46]	0.203	(0.194)	[0.30]
$\rho_{i,2} : i_{t-2}^T$	0.620	(0.231)	[0.01]	0.612	(0.182)	[0.00]
$\rho_{i,1} + \rho_{i,2}$	0.806	(0.061)	[0.00]	0.815	(0.057)	[0.00]
$\rho_u : u_{t-1}$	0.716	(0.190)	[0.00]	0.763	(0.162)	[0.00]
α	0.534	(0.179)	[0.00]	0.910	(0.323)	[0.01]
$\beta_1 : E_t \pi_{t+12} - \pi^*$	0.538	(0.157)	[0.00]	0.578	(0.147)	[0.00]
$\beta_2 : E_t y_{t+12} - y^*$	0.310	(0.119)	[0.01]	0.247	(0.084)	[0.00]
$\gamma_1 : SD(E_t \pi_{t+12})$				-0.992	(0.550)	[0.08]
$\gamma_2 : SD(E_t y_{t+12})$				-0.217	(0.323)	[0.50]
<i>Steady State Coefficients</i>						
Constant Term	2.75	(0.93)	[0.00]	4.91	(1.74)	[0.01]
$E_t \pi_{t+12} - \pi^*$	2.77	(0.81)	[0.00]	3.12	(0.79)	[0.00]
$E_t y_{t+12} - y^*$	1.60	(0.61)	[0.01]	1.33	(0.46)	[0.00]
$SD(E_t \pi_{t+12})$				-5.35	(2.97)	[0.08]
$SD(E_t y_{t+12})$				-1.17	(1.74)	[0.50]
R^2		0.97			0.97	
σ		0.33			0.33	
AIC		0.72			0.71	
SC		0.91			0.95	
Breusch-Godfrey Test	$\chi^2(4) = 3.6$ [0.46]			$\chi^2(4) = 7.2$ [0.13]		
White Test	$\chi^2(6) = 48.3$ [0.00]			$\chi^2(8) = 44.8$ [0.00]		
Standard Errors	White (1980)			White (1980)		

Notes: Estimation of (M1) (left panel) and (M2) (right panel) using OLS. Number of observations: 76. Steady state coefficients are obtained by setting $i_t^T = i_{t-1}^T = i_{t-2}^T$. σ : standard error of regression; AIC: Akaike information criterion; SC: Schwarz criterion.

4.3 The United Kingdom

Table 4 sets out the results for the United Kingdom. The estimates of the interest rate smoothing parameters are quite similar to those for the other two central banks (0.79 in the baseline specification and 0.82 in the augmented specification). The effect of persistent monetary policy shocks in the UK is similar to the EA with coefficients of 0.61 and 0.50 on the autoregressive error term. The Taylor principle is also met as the steady state estimates indicate a 2.3–3.1 pp increase to a 1 pp change in the expected inflation gap. The estimates of the expected output gap are larger

than for the other two central banks (2.3 in both specifications) indicating that the Bank of England (BoE) put more weight on output stabilization relative to inflation stabilization. Finally, the BoE also responds to inflation forecast uncertainty but not to growth forecast uncertainty.

Table 4: Taylor Rules for the United Kingdom

Dependent Variable: i_t^T	UK (M1)			UK (M2)		
	Coef.	S.E.	p-val.	Coef.	S.E.	p-val.
$\rho_{i,1} : i_{t-1}^T$	0.442	(0.253)	[0.09]	0.573	(0.153)	[0.00]
$\rho_{i,2} : i_{t-2}^T$	0.343	(0.189)	[0.07]	0.250	(0.155)	[0.11]
$\rho_{i,1} + \rho_{i,2}$	0.785	(0.113)	[0.00]	0.822	(0.090)	[0.00]
$\rho_u : u_{t-1}$	0.608	(0.204)	[0.00]	0.499	(0.176)	[0.01]
α	0.854	(0.540)	[0.12]	1.011	(0.600)	[0.10]
$\beta_1 : E_t \pi_{t+12} - \pi^*$	0.491	(0.228)	[0.04]	0.542	(0.148)	[0.00]
$\beta_2 : E_t y_{t+12} - y^*$	0.504	(0.114)	[0.00]	0.405	(0.106)	[0.00]
$\gamma_1 : SD(E_t \pi_{t+12})$				-1.117	(0.419)	[0.01]
$\gamma_2 : SD(E_t y_{t+12})$				-0.063	(0.510)	[0.90]
<i>Steady State Coefficients</i>						
Constant Term	3.97	(2.51)	[0.12]	5.69	(3.38)	[0.10]
$E_t \pi_{t+12} - \pi^*$	2.28	(1.06)	[0.04]	3.05	(0.83)	[0.00]
$E_t y_{t+12} - y^*$	2.34	(0.53)	[0.00]	2.28	(0.60)	[0.00]
$SD(E_t \pi_{t+12})$				-6.29	(2.36)	[0.01]
$SD(E_t y_{t+12})$				-0.36	(2.87)	[0.90]
R^2		0.95			0.96	
σ		0.32			0.30	
AIC		0.62			0.51	
SC		0.82			0.78	
Breusch-Godfrey Test	$\chi^2(4) = 10.5$ [0.03]			$\chi^2(4) = 3.8$ [0.43]		
White Test	$\chi^2(6) = 29.7$ [0.00]			$\chi^2(8) = 18.0$ [0.02]		
Standard Errors	Newey/West (1987)			White (1980)		

Notes: Estimation of (M1) (left panel) and (M2) (right panel) using OLS. Number of observations: 65. Steady state coefficients are obtained by setting $i_t^T = i_{t-1}^T = i_{t-2}^T$. σ : standard error of regression; AIC: Akaike information criterion; SC: Schwarz criterion.

4.4 Discussion

The uncertainty of inflation forecasts is negatively reflected in the reaction function of all three central banks. This finding is well in line with the derivation of the monetary policy reaction function in Section 2 and also in line with the previous literature for the Fed (Branch 2014; Milas and Martin 2009). The inclusion of the second moments of forecasts leads to a slightly better model fit with lower stan-

dard errors of regression, and improved information criteria seen in Tables 2–4. To underline the economic significance of forecast uncertainty we conduct a simple back-of-the-envelope-calculation and multiply the sample mean of inflation forecast uncertainty with the short-run estimate of γ_1 for each country. The fear of overshooting the inflation objective/target leads to a, *ceteris paribus*, $-0.45/ -0.27/ -0.31$ pp lower policy rate in case of the ECB/ Riksbank/ BoE.

Next, we evaluate the importance of forecast uncertainty in the central banks reaction functions over time. The left panel in Figures 1–3 shows the partial short-run effect of inflation expectation uncertainty and growth expectation uncertainty on the policy rate for the three central banks in each quarter. As already indicated by the small and insignificant coefficients for growth forecast uncertainty seen in Tables 2–4, the central bank policy rate is principally affected by the uncertainty of inflation forecasts. The peak effect of more than -0.75 pp is observed in the fourth quarter of 2008 when central banks worldwide aggressively cut their policy rates. However, even during relatively tranquil times the partial effect on the policy rate is around -0.25 pp.

The right panels in Figures 1–3 compare the combined short-run effect of inflation and growth forecast uncertainty on the policy rate with the combined partial short-run effects of the expected inflation gap and expected output gap. The figures indicate that the second moment of forecasts has a substantial influence on the policy rate even when compared to the level of macroeconomic forecasts. However, the reaction to the first moments is, on average, stronger, especially during the height of the financial crisis.

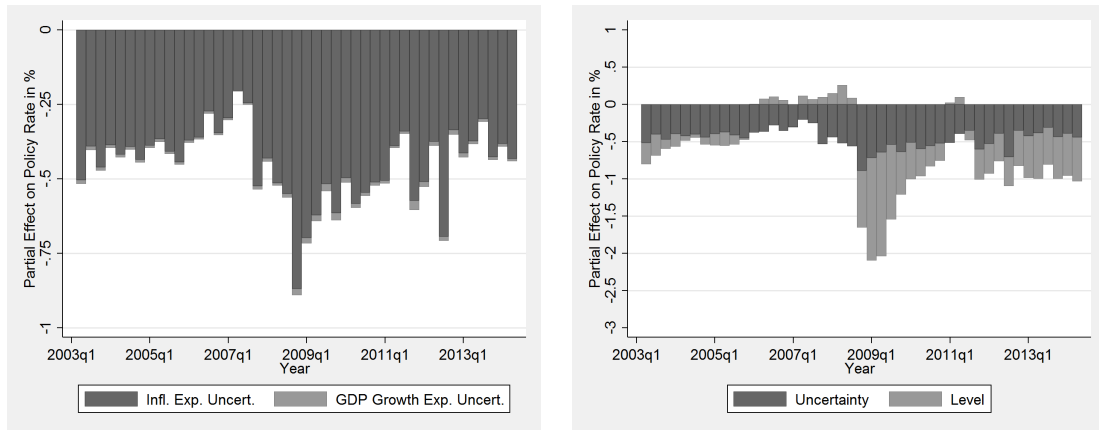


Figure 1: Partial Effect of Expectation Uncertainty on the Policy Rate in the EA

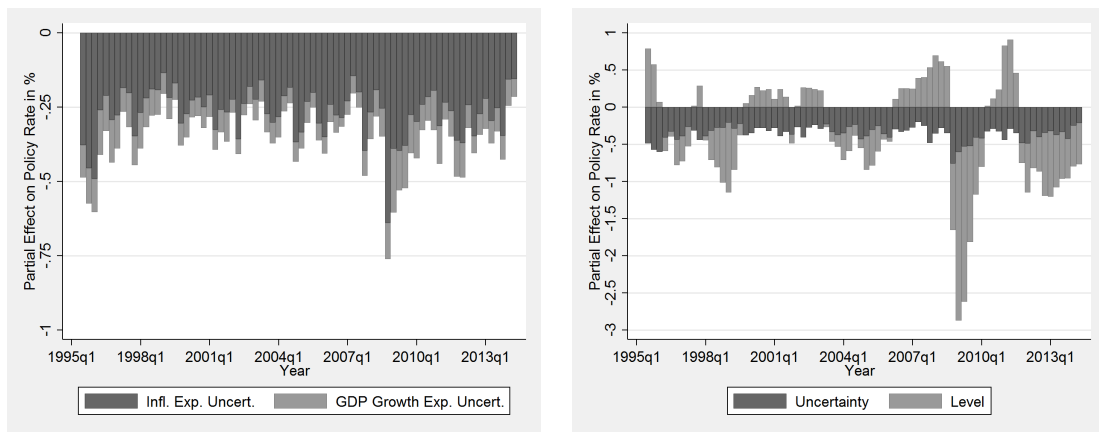


Figure 2: Partial Effect of Expectation Uncertainty on the Policy Rate in Sweden

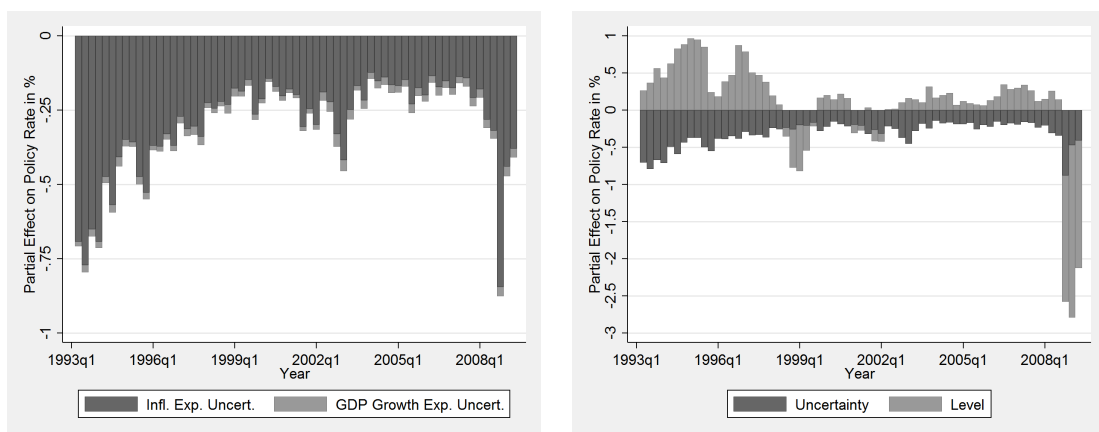


Figure 3: Partial Effect of Expectation Uncertainty on the Policy Rate in the UK

4.5 Robustness Test: Financial Crisis

Since our sample covers the recent economic and financial crisis we conduct a robustness test for the ECB and the Riksbank. In particular, we are interested in seeing if the reaction to forecast uncertainty changed after the fourth quarter of 2008. Arguably, that date marks the first time these two central banks reacted to the ongoing financial turmoil as the coordinated interest rate cut in October 2008 was the first clear indication that the financial crisis was affecting the ECB's and the Riksbank's interest rate policy. Table 5 sets out the estimates for a modification of (M2) which allows for separate estimates for the uncertainty of inflation forecasts and the uncertainty of growth forecasts before 2008Q4, denoted as $\gamma_{1,pre}$ and $\gamma_{2,pre}$, and thereafter, denoted as $\gamma_{1,cri}$ and $\gamma_{2,cri}$.

Table 5: Taylor Rules for the Euro Area and Sweden: Robustness Test

Dependent Variable: i_t^T	EA (M2 Split)			SWE (M2 Split)		
	Coef.	S.E.	p-val.	Coef.	S.E.	p-val.
$\rho_{i,1} : i_{t-1}^T$	0.446	(0.229)	[0.06]	0.589	(0.211)	[0.01]
$\rho_{i,2} : i_{t-2}^T$	0.374	(0.189)	[0.06]	0.242	(0.172)	[0.16]
$\rho_{i,1} + \rho_{i,2}$	0.820	(0.077)	[0.00]	0.831	(0.083)	[0.00]
$\rho_u : u_{t-1}$	0.507	(0.236)	[0.04]	0.561	(0.160)	[0.00]
α	0.930	(0.210)	[0.00]	0.830	(0.351)	[0.02]
$\beta_1 : E_t \pi_{t+12} - \pi^*$	0.354	(0.134)	[0.01]	0.431	(0.115)	[0.00]
$\beta_2 : E_t y_{t+12} - y^*$	0.171	(0.105)	[0.11]	0.137	(0.090)	[0.13]
$\gamma_{1,pre} : SD(E_t \pi_{t+12})$	-2.355	(1.462)	[0.12]	0.198	(0.578)	[0.73]
$\gamma_{1,cri} : SD(E_t \pi_{t+12})$	-3.029	(1.032)	[0.01]	-3.007	(1.083)	[0.01]
$\gamma_{1,pre} - \gamma_{1,cri}$	0.674	(1.896)	[0.72]	3.205	(0.982)	[0.00]
$\gamma_{2,pre} : SD(E_t y_{t+12})$	0.045	(1.453)	[0.98]	-0.870	(0.482)	[0.08]
$\gamma_{2,cri} : SD(E_t y_{t+12})$	-0.046	(0.512)	[0.93]	0.940	(0.485)	[0.06]
$\gamma_{2,pre} - \gamma_{2,cri}$	0.092	(1.513)	[0.95]	-1.810	(0.671)	[0.01]
R^2		0.98			0.98	
σ		0.20			0.30	
AIC		-0.17			0.55	
SC		0.23			0.86	
Breusch-Godfrey Test	$\chi^2(4) = 5.6$ [0.23]			$\chi^2(4) = 0.8$ [0.94]		
White Test	$\chi^2(10) = 24.3$ [0.01]			$\chi^2(10) = 55.9$ [0.00]		
Standard Errors	White (1980)			White (1980)		

Notes: Estimation of (M2) with separate coefficients for the pre-crisis period (until 2008Q3) and crisis period (starting in 2008Q4) using OLS. Number of observations: 45 (EA) and 76 (SWE). σ : standard error of regression; AIC: Akaike information criterion; SC: Schwarz criterion.

The ECB’s reaction to forecast uncertainty is statistically the same before and during the financial crisis. In case of the Riksbank, however, the reaction to inflation forecast uncertainty and growth forecast uncertainty is statistically different before 2008Q4 compared to the later subsample. In fact, the overall result for inflation forecast uncertainty in Table 3 is driven by the reaction during the financial crisis subsample as the Riksbank did not react significantly to inflation forecast uncertainty before 2008Q4 but very strongly thereafter. Interestingly, the Riksbank decreased its target rate in response to GDP growth forecast uncertainty before 2008Q4 and increased it after, thereby also partly offsetting the negative response to inflation forecast uncertainty during the financial crisis.

5 Conclusions

In this paper, we derive a modification of a forward-looking Taylor rule, which integrates two variables measuring the *uncertainty* of inflation and GDP growth *forecasts* into an otherwise standard New Keynesian model. We show that certainty-equivalence in New Keynesian models is a consequence of log-linearization and that a second-order Taylor approximation leads to a reaction function which includes the uncertainty of macroeconomic expectations. To test the model empirically, we rely on the dataset of individual forecasters provided by *Consensus Economics* and use the standard deviation of individual forecasts around the median forecast as proxy for forecast uncertainty. Our sample covers three economies (euro area, Sweden, and the United Kingdom) and the period 1992Q4–2014Q2.

We find that all three central banks significantly react to inflation forecast uncertainty but not to GDP growth forecast uncertainty. In line with the theoretical predictions, they reduce their policy rates in times of higher inflation expectation uncertainty, an indication that they feared overshooting the inflation objective more than undershooting it. The inclusion of the second moments of forecasts leads to a slightly better model fit, lower standard errors of regression, and an improvement of the information criteria in the regressions.

A simple back-of-the-envelope-calculation shows that the fear of overshooting the inflation objective/target leads to, *ceteris paribus*, a $-0.45/ -0.27/ -0.31$ pp lower policy rate in case of the ECB/ Riksbank/ BoE. The peak effect is more than -0.75 pp in the fourth quarter of 2008 when central banks worldwide aggressively cut their policy rates. Nevertheless, even during relatively tranquil times the partial

effect on the policy rate is around -0.25 pp. An in-depth analysis shows that the ECB's reaction to forecast uncertainty is statistically the same before and during the financial crisis, whereas, in case of the Riksbank the reaction to inflation forecast uncertainty and growth forecast uncertainty is statistically different before 2008Q4 when compared to the later subsample.

Our results have some implications for future research on optimal monetary policy rules as certainty-equivalence should not be taken as given. If the cautious behavior of central bankers is to be taken seriously, optimal policy rules of a Taylor type should take into account the uncertainty of macroeconomic variables. Anecdotal evidence (Greenspan 2004) and our results indicate that real policy behavior, indeed, accounts for the uncertainty of macroeconomic forecasts in accordance with our model's predictions.

Central bank watchers often use the Taylor rule as a short-hand expression to evaluate the stance of monetary policy. Consequently, our paper also has some implications for monetary policy observers. Neglecting the uncertainty around macroeconomic expectations might lead to a wrong assessment of the situation central bankers face at the time of their decision. Particularly in times of higher uncertainty, external observers might perceive monetary policy as too dovish if they ignore the second moment of macroeconomic variables in their assessment.

References

- [1] Ball, L., (1992): “Why Does Higher Inflation Raise Inflation Uncertainty?” *Journal of Monetary Economics* 29, 371–378.
- [2] Branch, W. A., 2014: “Nowcasting and the Taylor Rule,” *Journal of Money, Credit and Banking* 46, 1035–1055.
- [3] Capistran, C. (2008): “Bias in Federal Reserve Inflation Forecasts: Is the Federal Reserve Irrational or Just Cautious?” *Journal of Monetary Economics* 55, 1415–1427.
- [4] Clarida, R. H. (2001): “The Empirics of Monetary Policy Rules in Open Economies,” *International Journal of Finance and Economics* 6, 215–223.
- [5] Clarida, R., Gali, J., and Gertler, M. (1998): “Monetary Policy Rules in Practice: Some International Evidence,” *European Economic Review* 42, 1033–1067.
- [6] Coibion, O. and Gorodnichenko, Y. (2011): “Monetary Policy, Trend Inflation and the Great Moderation: An Alternative Interpretation,” *American Economic Review* 101, 341–370.
- [7] Coibion, O. and Gorodnichenko, Y. (2012): “Why are Target Interest Rate Changes so Persistent?” *American Economic Journal: Macroeconomics* 4, 126–162.
- [8] Collins, S. and Siklos, P. L. (2004): ”Optimal Monetary Policies and Inflation Targets: Are Australia, Canada and New Zealand different from the US?” *Open Economies Review* 15, 347–362.
- [9] Consolo, A. and Favero, C. A. (2009): “Monetary Policy Inertia: More a Fiction than a Fact?” *Journal of Monetary Economics* 56, 900–906.
- [10] Cukierman, A. and Meltzer, A. H. (1986): “A Theory of Ambiguity, Credibility and Inflation under Discretion and Asymmetric Information,” *Econometrica* 54, 1099–1128.
- [11] Friedman, M. (1977): “Nobel Lecture: Inflation and Unemployment,” *Journal of Political Economy* 85, 451–472.

- [12] Gali, J. (2008): “Monetary Policy, Inflation, and the Business Cycle: An Introduction to the New Keynesian Framework,” Princeton University Press: Princeton, NJ.
- [13] Gerlach, S. (2007): “Interest Rate Setting by the ECB, 1999–2006: Words and Deeds,” *International Journal Central Banking* 3, 1–45.
- [14] Gorter, J., Jacobs, J., and de Haan, J. (2008): “Taylor Rules for the ECB using Expectations Data,” *Scandinavian Journal of Economics* 110, 473–488.
- [15] Greenspan, A. (2004): “Risk and Uncertainty in Monetary Policy,” *American Economic Review* 94, 33–40.
- [16] Hodrick, R. J. and Prescott, E. C. (1997): “Postwar U.S. Business Cycles: An Empirical Investigation,” *Journal of Money, Credit and Banking* 29, 1–16.
- [17] Martin, C. and Milas, C. (2009): “Uncertainty and Monetary Policy Rules in the United States,” *Economic Inquiry* 47, 206–215.
- [18] Neuenkirch, M. and Siklos, P. L. (2013): “What’s in a Second Opinion? Shadowing the ECB and the Bank of England,” *European Journal of Political Economy* 32, 135–148.
- [19] Neuenkirch, M. and Tillmann, P. (2014): “Inflation Targeting, Credibility, and Non-linear Taylor Rules,” *Journal of International Money and Finance* 41, 30–45.
- [20] Newey, W. K. and West, K. D. (1987): “A Simple, Positive Semi-definite, Heteroskedasticity and Autocorrelation Consistent Covariance Matrix,” *Econometrica* 55, 703–708.
- [21] Nobay, A. R. and Peel, D. A. (2003): “Optimal Discretionary Monetary Policy in a Model with Asymmetric Central Bank Preferences,” *The Economic Journal* 113, 657–665.
- [22] Orphanides, A. (2001): “Monetary Policy Rules Based on Real-time Data,” *American Economic Review* 91, 964–985.
- [23] Orphanides, A. (2003): “Monetary Policy Evaluation with Noisy Information,” *Journal of Monetary Economics* 50, 605–631.

- [24] Orphanides, A. and van Norden, S. (2002): “The Unreliability of Output-Gap Estimates in Real Time,” *Review of Economics and Statistics* 84, 569–583.
- [25] Patton, A. and Timmermann, A. G. (2007): “Properties of Optimal Forecasts under Asymmetric Loss and Nonlinearity,” *Journal of Econometrics* 140, 884–918.
- [26] Pourgerami, A. and Maskus, K. (1987): “The Effects of Inflation on the Predictability of Price Changes in Latin America: Some Estimates and Policy Implications,” *World Development* 15, 287–290.
- [27] Rudebusch, G. D. (2006): “Monetary Policy Inertia: A Fact or Fiction?” *International Journal of Central Banking* 2, 85–135.
- [28] Ruge-Murcia, F. J. (2003): “Inflation Targeting under Asymmetric Preferences,” *Journal of Money, Credit and Banking* 25, 763–785.
- [29] Surico, P. (2007a): “The Fed’s Monetary Policy Rule and U.S. Inflation: The Case of Asymmetric Preferences,” *Journal of Economic Dynamics and Control* 31, 305–324.
- [30] Surico, P. (2007b): “The Monetary Policy of the European Central Bank,” *Scandinavian Journal of Economics* 109, 115–135.
- [31] Svensson, L.E.O. and Woodford, M. (2003): “Indicator Variables for Optimal Policy,” *Journal of Monetary Economics* 50, 691–720.
- [32] Swanson, E. T. (2004): “Signal Extraction and Non-Certainty-Equivalence in Optimal Monetary Policy Rules,” *Macroeconomic Dynamics* 8, 27–50.
- [33] Taylor, J. B. (1993): “Discretion versus Policy Rules in Practice,” *Carnegie-Rochester Conference Series on Public Policy* 39, 195–214.
- [34] Ungar, M. and Zilberfarb, B.-Z. (1993), “Inflation and its Unpredictability—Theory and Empirical Evidence,” *Journal of Money, Credit and Banking* 25, 709–720.
- [35] Walsh, C. E. (2010): “*Monetary Theory and Policy*,” MIT Press, Cambridge, MA.
- [36] White, H. (1980): “A Heteroskedasticity-Consistent Covariance Matrix Estimator and a Direct Test for Heteroskedasticity,” *Econometrica* 48, 817–838.

Appendix

Table A1: Descriptive Statistics

Euro Area	Mean	Median	Std. Dev.	Min.	Max.
i_t	1.89	2.00	1.18	0.15	4.25
$E_t\pi_{t+12}$	1.78	1.83	0.49	0.65	2.90
$E_t y_{t+12}$	1.07	1.35	1.08	-2.34	2.55
$SD(E_t\pi_{t+12})$	0.16	0.15	0.04	0.07	0.30
$SD(E_t y_{t+12})$	0.25	0.22	0.11	0.08	0.66
Sweden	Mean	Median	Std. Dev.	Min.	Max.
i_t	3.04	2.95	1.97	0.25	8.91
$E_t\pi_{t+12}$	1.63	1.64	0.77	-0.30	3.58
$E_t y_{t+12}$	2.40	2.57	1.10	-2.18	4.11
$SD(E_t\pi_{t+12})$	0.28	0.26	0.09	0.14	0.64
$SD(E_t y_{t+12})$	0.39	0.36	0.15	0.14	0.99
United Kingdom	Mean	Median	Std. Dev.	Min.	Max.
i_t	5.19	5.25	1.35	0.50	7.50
$E_t\pi_{t+12}$	2.42	2.33	0.52	1.15	3.50
$E_t y_{t+12}$	2.19	2.43	1.07	-2.58	3.31
$SD(E_t\pi_{t+12})$	0.28	0.22	0.16	0.11	0.80
$SD(E_t y_{t+12})$	0.37	0.37	0.10	0.19	0.69

Table A2: Correlation Matrixes

Euro Area	i_t	$E_t\pi_{t+12}$	$E_t y_{t+12}$	$SD(E_t\pi_{t+12})$	$SD(E_t y_{t+12})$
i_t	1.00				
$E_t\pi_{t+12}$	0.62	1.00			
$E_t y_{t+12}$	0.50	0.53	1.00		
$SD(E_t\pi_{t+12})$	-0.21	-0.27	-0.59	1.00	
$SD(E_t y_{t+12})$	-0.36	-0.40	-0.74	0.67	1.00

Sweden	i_t	$E_t\pi_{t+12}$	$E_t y_{t+12}$	$SD(E_t\pi_{t+12})$	$SD(E_t y_{t+12})$
i_t	1.00				
$E_t\pi_{t+12}$	0.67	1.00			
$E_t y_{t+12}$	0.16	0.32	1.00		
$SD(E_t\pi_{t+12})$	0.20	0.17	-0.42	1.00	
$SD(E_t y_{t+12})$	0.09	-0.09	-0.57	0.40	1.00

United Kingdom	i_t	$E_t\pi_{t+12}$	$E_t y_{t+12}$	$SD(E_t\pi_{t+12})$	$SD(E_t y_{t+12})$
i_t	1.00				
$E_t\pi_{t+12}$	0.60	1.00			
$E_t y_{t+12}$	0.58	0.38	1.00		
$SD(E_t\pi_{t+12})$	0.03	0.39	-0.28	1.00	
$SD(E_t y_{t+12})$	-0.40	-0.08	-0.33	0.15	1.00

Notes: Correlations in bold are significant at the ten percent level.

Table A3: Taylor Rules using the Variance of Individual Forecasts

Dependent Variable: i_t^T	EA (M2 Variance)			SWE (M2 Variance)			UK (M2 Variance)		
	Coef.	S.E.	p-val.	Coef.	S.E.	p-val.	Coef.	S.E.	p-val.
$\rho_{i,1} : i_{t-1}^T$	0.560	(0.217)	[0.01]	0.358	(0.196)	[0.07]	0.638	(0.159)	[0.00]
$\rho_{i,2} : i_{t-2}^T$	0.316	(0.182)	[0.09]	0.472	(0.182)	[0.01]	0.185	(0.158)	[0.25]
$\rho_{i,1} + \rho_{i,2}$	0.876	(0.053)	[0.00]	0.830	(0.053)	[0.00]	0.822	(0.084)	[0.00]
$\rho_u : u_{t-1}$	0.405	(0.234)	[0.09]	0.734	(0.137)	[0.00]	0.445	(0.190)	[0.02]
α	0.658	(0.157)	[0.00]	0.746	(0.221)	[0.00]	0.883	(0.506)	[0.09]
$\beta_1 : E_t \pi_{t+12} - \pi^*$	0.320	(0.115)	[0.01]	0.531	(0.115)	[0.00]	0.497	(0.139)	[0.00]
$\beta_2 : E_t y_{t+12} - y^*$	0.162	(0.085)	[0.06]	0.197	(0.076)	[0.01]	0.379	(0.104)	[0.00]
$\gamma_1 : Var(E_t \pi_{t+12})$	-10.245	(3.065)	[0.00]	-2.499	(1.035)	[0.02]	-1.414	(0.544)	[0.01]
$\gamma_2 : Var(E_t y_{t+12})$	-0.081	(0.595)	[0.89]	-0.129	(0.388)	[0.74]	-0.305	(0.598)	[0.61]
R^2	0.98			0.97			0.96		
σ	0.19			0.31			0.29		
AIC	-0.32			0.61			0.50		
SC	0.00			0.86			0.77		
Breusch-Godfrey Test	$\chi^2(4) = 1.9$ [0.75]			$\chi^2(4) = 7.3$ [0.12]			$\chi^2(4) = 4.1$ [0.40]		
White Test	$\chi^2(8) = 20.8$ [0.01]			$\chi^2(8) = 41.4$ [0.00]			$\chi^2(8) = 15.2$ [0.06]		
Standard Errors	White (1980)			White (1980)			White (1980)		

Notes: Estimation of (M2) with the variance (instead of the standard deviation) of individual forecasts using OLS. Number of observations: 45 (EA), 76 (SWE), and 65 (UK). σ : standard error of regression; AIC: Akaike information criterion; SC: Schwarz criterion.

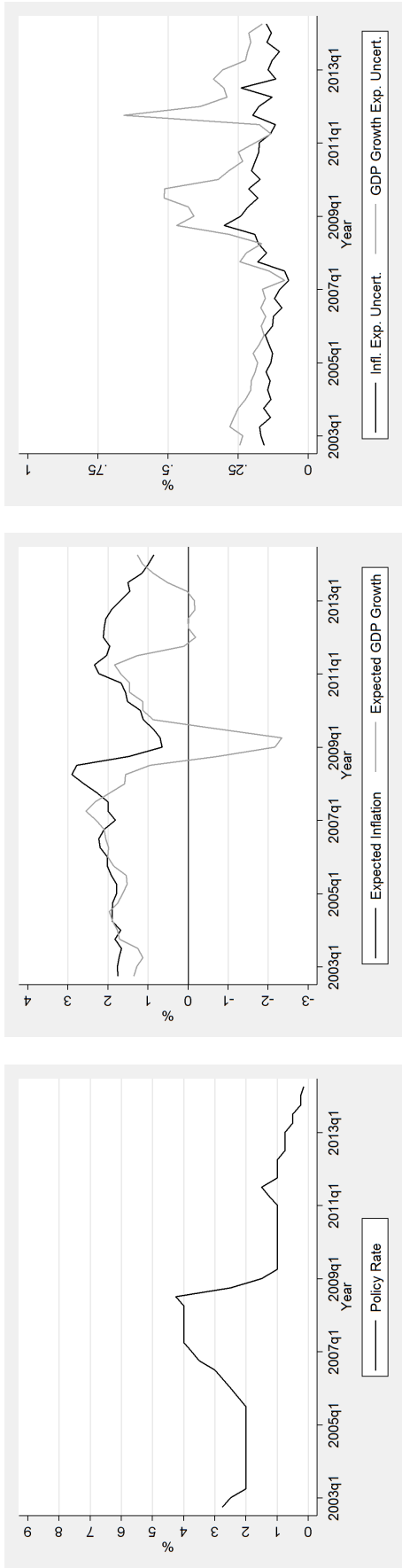


Figure A1: Policy Rate, Inflation and Growth Expectations, and Uncertainty of Expectations for the Euro Area

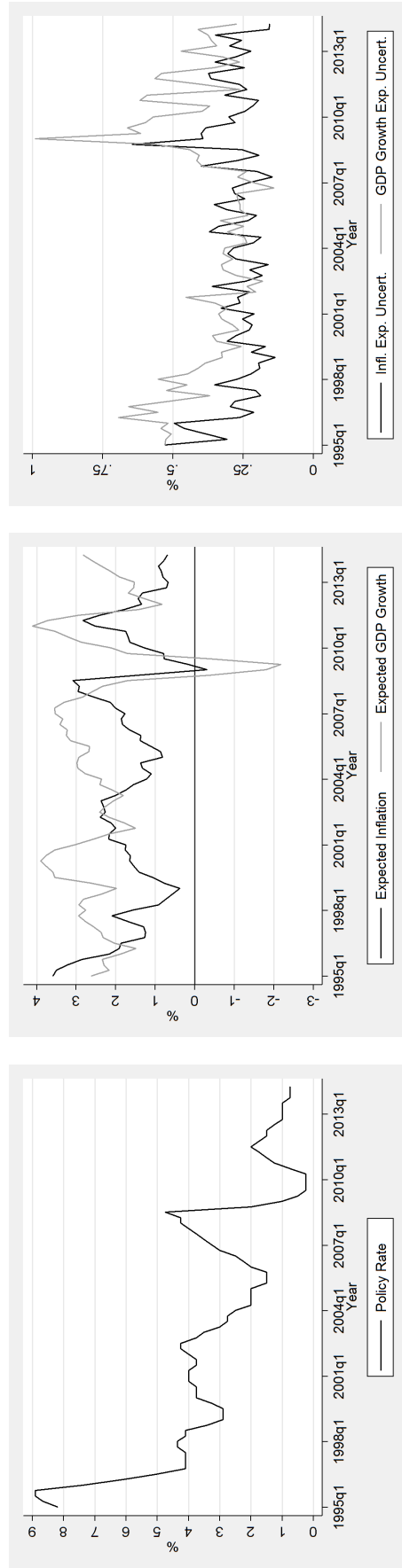


Figure A2: Policy Rate, Inflation and Growth Expectations, and Uncertainty of Expectations for Sweden

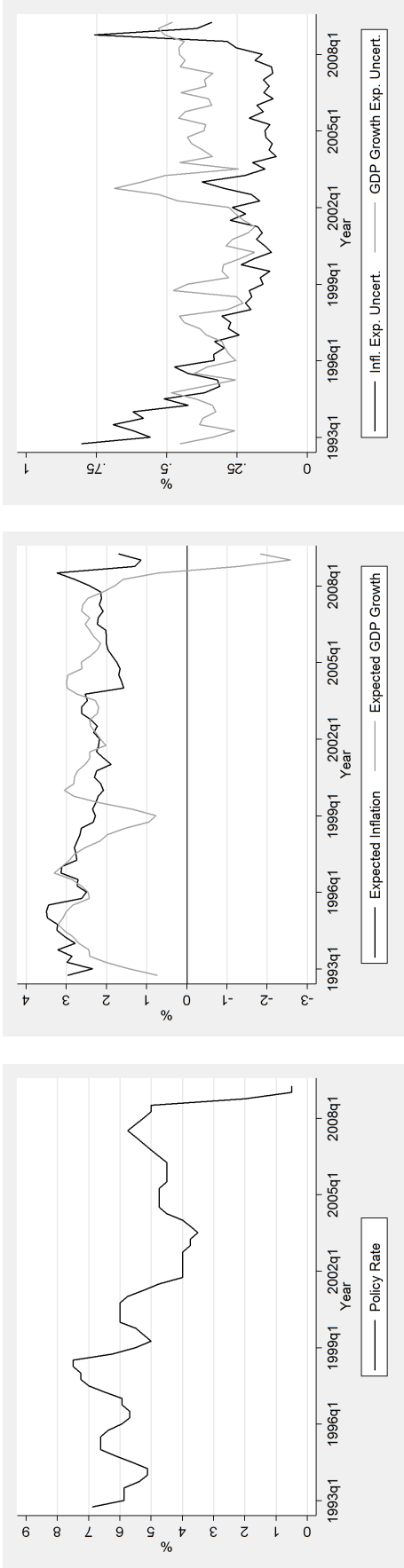


Figure A3: Policy Rate, Inflation and Growth Expectations, and Uncertainty of Expectations for the United Kingdom