Inflation Persistence and Robust Monetary Policy Design

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Abstract

This paper examines the performance of optimised interest-rate rules when there is uncertainty about a key determinant of the monetary transmission mechanism, namely the degree of persistence characterising the inflation process. The paper focuses on the euro area and utilises two variants of an estimated small-scale macroeconomic model featuring distinct types of staggered contracts specifications which induce quite different degrees of inflation persistence. The paper shows that a cautious monetary policy-maker is well-advised to design and implement interest-rate policies under the assumption that inflation persistence is high when there is considerable uncertainty about the prevailing degree of inflation persistence. Such policies are characterised by a relatively aggressive response to inflation developments and exhibit a substantial degree of inertia.

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1 Introduction

There is an active and rapidly growing literature on the evaluation of structural models of inflation determination.[1] While theoretical models, starting with the staggered contracts models of Taylor (1980) and Calvo (1983), propose that current inflation depends on future inflation and a measure of current demand or cost pressures, recent empirical research has highlighted that these models, at least in their simplest specification, typically fail to explain the high degree of inflation persistence observed in the data. In fact, most empirical studies that have focused on estimating variants of the New-Keynesian Phillips Curve (NKPC), based on either Taylor or Calvo-type staggered contracts, have obtained highly significant estimates of the coefficient on lagged inflation.

At the same time, Taylor (2000) and Cogley and Sargent (2001) have observed that the degree of persistence in U.S. inflation has been drifting downward in the 1980s and 1990s as inflation has come under control. Taylor (2000) suggests that the diminished degree of inflation persistence may be due to changes in the orientation of monetary policy. In an environment with a stable and transparent monetary policy regime, inflation expectations may become contained and, hence, price and wage setters may be less inclined to change their contracts in response to shocks. Similarly, Brayton, Roberts and Williams (1999) argue that globalisation has increased competition in the products markets, thereby squeezing mark-ups and yielding reductions in prices. Although Staiger, Stock and Watson (2001) do not find empirical evidence in favour of such theories, more favourable evidence may emerge as data from the low-inflation regime accumulate.

In the light of the ongoing controversy about the appropriate specification of structural models of inflation determination and more recent indications that the law of motion for inflation may have altered, this paper investigates the performance of simple monetary policy rules when the monetary policy-maker is faced with uncertainty about the degree of persistence characterising the inflation process. The degree of inflation persistence represents a

[1] See for example the evaluations by Galí and Gertler (1999), Guerrieri (2005), Sbordone (2002), Rudd and Whelan (2002) and Cogley and Sbordone (2004) for the United States and the studies by Galí, Gertler and López-Salido (2001) and Coenen and Wieland (2005) for the euro area.

key determinant of the monetary transmission mechanism and has important implications for the ability of monetary policy to stabilise inflation relative to output. Hence, monetary policy rules should ideally be designed to perform reasonably well under a range of alternative models of inflation determination which differ with respect to the degree of inflation persistence that they induce.

To examine the consequences of different degrees of inflation persistence for the performance of monetary policy rules, we concentrate on the euro area for which such an examination seems particularly relevant. First, the euro area is a new and relatively unexplored entity and, hence, the European Central Bank (ECB), with its rather short history, faces substantial uncertainty about the characteristics of the aggregate euro area inflation process. And second, the mixed empirical evidence based on data for individual euro area member states provides no clear indication of what type of model should be chosen for modelling the aggregate inflation process.

Against this background, we utilise two variants of the small-scale euro area model developed by Coenen and Wieland (2005) which feature different types of staggered contracts specifications: the nominal wage contracting specification due to Taylor (1980) and the relative real wage contracting specification originally proposed by Buiter and Jewitt (1981) and adapted to empirical work by Fuhrer and Moore (1995).[2] These two contracting specifications differ with respect to the degree of inflation persistence that they induce, because relative real wage contracts give more weight to past inflation.[3]

Comparing the euro area results to those obtained for France, Germany and Italy sepa-

[2]Thus, the estimated small-scale euro area model belongs to the class of New-Keynesian models which have gained increased popularity in macroeconomic modelling over the recent years. This class of models includes most of the smaller-scale models currently used for research on monetary policy (see for example the backward-looking model of Rudebusch and Svensson, 1999; the models with rational expectations and nominal rigidities of Fuhrer and Moore, 1995; Fuhrer, 1997; and Coenen, Orphanides and Wieland, 2004) and the models with optimising agents of Rotemberg and Woodford (1997, 1999), McCallum and Nelson (1999), Christiano, Eichenbaum and Evans (2005) and Smets and Wouters (2003), as well as large-scale policy models such as the Federal Reserve Board's FRB/U.S. model (see Brayton and Tinsley, 1996) the ECB's Area-Wide Model (see Fagan, Henry and Mestre, 2005) or the multi-country model of Taylor (1993a).

[3]There are other mechanisms which have been proposed in the literature as a means of inducing lag-dependent inflation dynamics. For example, Galí and Gertler (1999) allow for a fraction of backward-looking firms in the staggered nominal contracts model of Calvo (1983), which are assumed to follow a "rule of thumb" when changing their prices, while Christiano, Eichenbaum and Evans (2005) assume that nominal contracts are indexed to past inflation.

rately, Coenen and Wieland (2005) show that the relative real wage contracting specification does quite well in countries which transitioned out of a high inflation regime such as France and Italy, while the nominal wage contracting specification describes German data better which exhibit a substantially lower degree of inflation persistence. This finding may be attributed to different degrees of nominal rigidity in the price and wage-setting behaviour across economies, but it may also reflect different degrees of credibility of the respective monetary regimes over the estimation period.[4]

Thus, as far as the future of the European Monetary Union (EMU) is concerned, the estimation based on historical euro area data may overstate the case for the relative real wage contracting model. In this case, nominal rigidities à la Taylor may provide a better description of the inflation process than Fuhrer-Moore-type rigidities and, in terms of evaluating alternative monetary policy strategies, a policy-maker who is optimistic about the output losses associated with stabilising inflation may prefer to use the nominal wage contracting specification, while a pessimist may prefer the relative real wage contracting specification.[5] Given the high degree of uncertainty about the determination of euro area inflation, however, a robust monetary policy strategy for the euro area should perform reasonably well under both types of contracting specifications.

In terms of methodology, this paper builds on recent work by Levin, Wieland and Williams (1999, 2003) – henceforth referred to as LWW (1999, 2003) – evaluating the performance and robustness of simple monetary policy rules across five different models of the U.S. economy.[6] This methodology involves implementing simple reaction functions describing the response of the short-term nominal interest rate to inflation and the output gap,

[4] To the extent that the observed wage and price-setting behaviour actually depends on the characteristics of the monetary policy regime, the contracting specification itself would need to be endogenised. While considering such endogeneity seems desirable, this is beyond the scope of this paper.

[5] Another hypothesis, though with similar consequences, is that due to heterogeneity in the persistence of the national inflation rates in the countries that form the euro area, the use of aggregated euro area inflation data induces an upward bias in the estimated degree of inflation persistence. The latter would be an empirical artefact and therefore considered misleading as regards the evaluation of alternative monetary policy strategies.

[6] There are alternative approaches to analysing the consequences of uncertainty about the structure of the economy (see for example Giannoni, 2002; Giannoni and Woodford, 2002; Hansen and Sargent, 2005; Onatski and Stock, 2002; Onatski and Williams, 2003; and Tetlow and von zur Muehlen, 2001). This coexistence of alternative approaches reflects the fact that there has not yet emerged a consensus on how to address the issue of model uncertainty.

either observed or forecast, and then optimising over the respective response coefficients. The performance of these optimised interest-rate rules is then evaluated with regard to their ability to stabilise inflation and output around their targets, while avoiding undue fluctuations in the nominal interest rate itself.[7]

Unlike the papers by LWW, this paper focuses on one particular determinant of the monetary transmission mechanism, namely the degree of inflation persistence that is induced by alternative models of inflation determination. Thus, while LWW consider a larger set of models which exhibit substantial differences in theoretical specification, in degree of aggregation, in estimation sample and in estimation methodology, we control for all differences except for the different degrees of structural inflation persistence induced by the two distinct staggered contracts specifications. As a result, any differences in our findings can be attributed to the different degrees of inflation persistence induced by the two types of contracting specifications.

We start our analysis by comparing the characteristics of inflation and output-gap dynamics under the two distinct staggered contracts specifications with an empirical benchmark policy rule imposed. To this end, we report the responses of inflation and the output gap to an unexpected tightening of monetary policy to illustrate the implied differences in the transmission of monetary policy. Our subsequent analysis proceeds in two steps. Following the methodology proposed by LWW, we first evaluate the stabilisation performance of both outcome and forecast-based interest-rate rules which are designed for each of the two staggered contracts specifications separately. We then examine the robustness of these optimised interest-rate rules in a situation when the monetary policy-maker does not know which of the two staggered contracts specifications represents the "true" model of the inflation process. Specifically, we consider two distinct sources of making policy mistakes. First, the policy-maker is confronted with uncertainty as to which of the two contracting specifications to rely upon when designing interest-rate rules geared towards stabilising inflation relative to output. And second, in the case of forecast-based rules, the

[7]Earlier studies of the performance of interest-rate rules across a range of macroeconomic models of the U.S. economy are provided in Bryant, Hooper and Mann (1993) and Taylor (1999).

policy-maker is confronted with uncertainty regarding the choice of the forecasting model needed to implement a given forecast-based interest-rate rule. Of course, the second type of mistake is most likely to occur in combination with the first.

Based on our analysis, we conclude that it may be very risky to rely too heavily on interest-rate rules which are designed and implemented under the assumption that the degree of structural inflation persistence is low. Following the prescriptions of such rules may result in very poor stabilisation outcomes if the true inflation process turns out to be considerably more persistent; that is, when the policy-maker is *underestimating* the degree of inflation persistence. In contrast, rules which are designed and implemented under the assumption that the degree of inflation persistence is relatively high also perform reasonably well if inflation is considerably less persistent; that is, when *overestimating* the degree of inflation persistence. Hence, a cautious monetary policy-maker is well-advised to take monetary policy decisions under the assumption that the inflation process is characterised by a high degree of persistence until strong evidence in favour of a low-persistence regime has emerged.[8] While forecast-based rules may result in particularly poor stabilisation outcomes if they are implemented using forecasts from a model that largely underpredicts the degree of persistence, we show that pooling of forecasts from a possibly diverse set of models, rather than relying on any single model's forecast, can serve as a means of insuring the policy-maker against risks arising from the use of the wrong forecasting model.

Finally, we identify the operating characteristics of simple interest-rate rules that are robust in a situation characterised by substantial uncertainty about the degree of inflation persistence. To this end, we optimise the interest-rate response coefficients across the two contracting specifications simultaneously. Our results show that robust rules are tilted towards the specification that induces a high degree of persistence. Specifically, we show that robust rules are characterised by a relatively aggressive response to inflation and exhibit a substantial degree of inertia. Incidentally, we find that a relatively aggressive first-difference

[8]In a related study, Leitemo (2005) shows, within a stylised New-Keynesian model, that a monetary policy-maker who is restricted to act under discretion can eventually enhance the effectiveness of monetary policy by overestimating the true degree of inflation persistence. The reason is that such misperception helps to increase the degree of policy inertia which is sup-optimally low under discretion.

rule, which relates changes in the short-term nominal interest rate to the one-year-ahead forecast of inflation and the current output gap already goes a long way towards making monetary policy robust. To the extent that such a rule performs remarkably well under both types of contracts and in the light of the substantial uncertainty about how to model euro area inflation, we tentatively conclude that such a rule may serve as a useful benchmark for model-based evaluations of monetary policy in the euro area.

The remainder of this paper is organised as follows. Section 2 outlines the behavioural equations of the euro area model with the two distinct staggered contracts specifications and illustrates the implied differences in inflation and output-gap dynamics under an estimated benchmark rule. Section 3 briefly describes the methodology used for evaluating the performance of simple interest-rate rules and provides a set of optimised benchmark rules for each of the two staggered contracts models. Section 4 evaluates the robustness of these optimised benchmark rules when there is uncertainty about the prevailing degree of inflation persistence, while Section 5 identifies the operating characteristics of simple interest-rate rules that perform reasonably well in such an environment. Section 6 concludes and discusses some directions for future research.

2 Two Models of Inflation Determination

To analyse the robustness of monetary policy rules when there is uncertainty about the degree of inflation persistence, we utilise two variants of the small-scale euro area model developed by Coenen and Wieland (2005). The first variant employs the nominal wage contracting specification due to Taylor (1980), and the second the relative real wage contract specification originally proposed by Buiter and Jewitt (1981) and adapted to empirical work by Fuhrer and Moore (1995). Both types of contracting specifications are found to describe historical euro area data reasonably well.

2.1 The Behavioural Equations

The behavioural equations of the small-scale euro area model are indicated in **Table 1**. As shown in model equation (M-1), the aggregate price level p_t is determined as a weighted

Table 1: A Small-Scale Euro Area Model with Staggered Wage Contracts

Price level	$p_t = f_0\, x_t + f_1\, x_{t-1} + f_2\, x_{t-2} + f_3\, x_{t-3},$	(M-1)
	where $f_i = 0.25 + (1.5 - i)\, s,\ s \in (0,\ 1/6]$	
Contract wage		
Taylor	$x_t = \mathrm{E}_t \left[\sum_{i=0}^{3} f_i\, p_{t+i} + \gamma \sum_{i=0}^{3} f_i\, y_{t+i} \right] + \epsilon_t^x$	(M-2a)
Fuhrer-Moore	$x_t - p_t = \mathrm{E}_t \left[\sum_{i=0}^{3} f_i\, v_{t+i} + \gamma \sum_{i=0}^{3} f_i\, y_{t+i} \right] + \epsilon_t^x,$	(M-2b)
	where $v_t = \sum_{i=0}^{3} f_i\, (x_{t-i} - p_{t-i})$	
Aggregate demand	$y_t = \delta_1\, y_{t-1} + \delta_2\, y_{t-2} + \phi\, (r_{t-1}^l - r^*) + \epsilon_t^d,$	(M-3)
	where $y_t = q_t - q_t^*$	
Term structure	$i_t^l = \mathrm{E}_t \left[\frac{1}{8} \sum_{i=0}^{7} i_{t+i}^s \right]$	(M-4)
Fisher equation	$r_t^l = i_t^l - \mathrm{E}_t \left[\frac{1}{8} \sum_{i=1}^{8} \pi_{t+i} \right],$	(M-5)
	where $\pi_t = 4\, (p_t - p_{t-1})$	

Note: p: aggregate price level; x: nominal contract wage; y: output gap; ϵ^x: contract wage shock; v: real contract wage index; r^l: long-term real interest rate; r^*: equilibrium real interest rate; ϵ^d: aggregate demand shock; q: actual output; q^*: potential output; i^l: long-term nominal interest rate; i^s: short-term nominal interest rate; π: one-quarter inflation. Prices, wages and output are expressed in logarithmic form, and interest rates and inflation are expressed at annualised rates.

average of staggered nominal wage contracts signed over the past year, x_{t-i} $(i = 0, 1, 2, 3)$, which are still in effect in period t.[9] Following Fuhrer and Moore (1995), the weights f_i on contract wages from different periods are assumed to be a downward-sloping linear function of contract length. This function depends on a single parameter, the slope s.

The staggered contracts models of Taylor and Fuhrer and Moore induce nominal rigidities because workers negotiate long-term contracts and compare the contract wage to past contracts that are still in effect and future contracts that will be negotiated over the life of this contract. As a result only a subset of nominal wage contracts are adjustable at a

[9]Thus, like Fuhrer and Moore (1995), we treat the aggregate price and aggregate wage indices interchangeably, which is consistent with a fixed mark-up. For recent studies considering wage and price stickiness separately, see Taylor (1993a), Erceg, Henderson and Levin (2000) and Amato and Laubach (2003).

given point in time. The distinction between Taylor and Fuhrer-Moore-type wage contracts concerns the definition of the wage indices that form the basis of this comparison.

Under Taylor's specification defined by equation (M-2a), the nominal wage contract x_t is negotiated with reference to the price level that is expected to prevail over the life of the contract, p_{t+i}, as well as the expected output gap over this period, y_{t+i}. The operator $\mathrm{E}_t[\,\cdot\,]$ indicates the model-consistent expectation, or forecast, of a particular variable conditional on all information available in period t.[10] Since the price indices p_{t+i} reflect contemporaneous and preceding contract wages, (M-2a) implies that wage setters look at an average of nominal contract wages negotiated in the recent past and expected to be negotiated in the near future when setting the current contract wage. In other words, they take into account nominal wages that apply to overlapping contracts. If wage setters expect the output gap to be positive, $y_{t+i} > 0$, they adjust the current contract wage upwards relative to overlapping contracts; and vice versa. The sensitivity of contract wages to the output gap is measured by γ. The contract wage shock ϵ_t^x is assumed to be serially uncorrelated.

Under the Fuhrer-Moore specification defined by equation (M-2b), workers negotiating their nominal wage compare the implied real wage expected to prevail over the life of their contract with the real wages on overlapping contracts in the recent past and near future. This specification implies that the expected real wage under contracts signed in the current period is set with reference to an average of real contract wage indices expected to prevail over the current and the next three quarters, v_{t+i}.[11] Thus, the Fuhrer-Moore contracts should not be understood as reflecting real wage rigidity, but rather as representing an alternative nominal rigidity.

Equations (M-1) and (M-2a, M-2b) represent rules for price and contract wage-setting that are not explicitly derived from a framework with optimising agents. However, they need not necessarily be inconsistent with such a framework. More recently, Taylor-style staggered

[10] We employ the AIM algorithm of Anderson and Moore (1985), which uses the Blanchard and Kahn (1980) method for solving linear rational expectations models, to compute model-consistent forecasts.

[11] Here we follow Fuhrer and Moore (1995) and use the current price level in the definition of the real contract wage instead of using the average price level expected to prevail over the life of the contract, which would be theoretically preferable. For a more detailed discussion of variations of relative real wage contracts see Coenen and Wieland (2005).

contracts have been analysed within more fully fleshed-out dynamic general equilibrium models (see for example Chari, Kehoe and McGrattan, 2000; or King and Wolman, 1999). Starting with a representative agent model with monopolistically competitive firms these studies add the constraint that *prices*, rather than *wages* are set in a staggered fashion for a fixed number of periods. A log-linear approximation of a stripped-down version of these equilibrium models then implies a contract price equation that coincides with Taylor's contract wage equation (M-2a) with the parameter γ being a function of deeper technology and preference parameters. The Fuhrer-Moore contracting model, however, has typically been criticised for lacking such microeconomic foundations.

To complete our macroeconomic model of the euro area, it remains to specify aggregate demand and the transmission of monetary policy. As regards the determination of aggregate demand, equation (M-3) relates the output gap, that is, the deviation of actual output from its potential, $y_t = q_t - q_t^*$, to two lags of itself and to the lagged ex-ante long-term real interest rate r_{t-1}^l. Since our analysis is focused on the implications of different types of staggered contracts specifications we assume for simplicity that potential output q_t^* is exogenous. In the short run, actual output q_t may deviate from its long-run potential due to the nominal rigidities arising from the staggering of contracts. The demand shock ϵ_t^d is assumed to be serially uncorrelated. The rationale for including lags of the output gap is to account for habit formation in consumption as well as adjustment costs and accelerator effects in investment. We use the lagged instead of the contemporaneous value of the long-term real interest rate to allow for a transmission lag of monetary policy.

Two equations relate the long-term real interest rate r_t^l to the short-term nominal interest rate i_t^s, which is assumed to be the principal instrument of monetary policy. First, as to the determination of the long-term nominal interest rate i_t^l defined by equation (M-4), we rely on the accumulated forecasts of the short-term interest rate over two years. These accumulated forecasts will coincide with the long-term interest-rate forecast for this horizon under the expectations hypothesis of the term structure. The term premium is assumed to be constant and equal to zero. And second, according to the Fisher relation defined by equation (M-5), we obtain the ex-ante long-term real interest rate r_t^l by subtracting

Table 2: The Parameter Estimates of the Small-Scale Euro Area Model

A. Aggregate supply [(a)]	s	γ		p-value [(c)]
Taylor contracts	0.0456	0.0115		0.3186 [2]
	(0.0465)	(0.0053)		
Fuhrer-Moore contracts	0.0742	0.0212		0.2602 [2]
	(0.0245)	(0.0048)		
B. Aggregate demand [(b)]	δ_1	δ_2	ϕ	p-value [(c)]
	1.1807	-0.2045	-0.0947	0.2307 [5]
	(0.1006)	(0.1065)	(0.0333)	

Note: [(a)] Simulation-based indirect estimates using a VAR(3) model for the annualised one-quarter inflation rate and the output gap as auxiliary model. Estimated standard errors are given in parentheses. Sample period: 1974Q4 to 1998Q4. [(b)] GMM estimates using a constant, lagged values of the output gap, the annualised one-quarter inflation rate and the short-term nominal interest rate as instruments. Estimated standard errors are given in parentheses. Sample period: 1974Q4 to 1997Q1. [(c)] Probability values associated with the tests of overidentifying restrictions. Numbers of overidentifying restrictions are given in brackets.

inflation expectations over the following two years, with $\pi_{t+i} = 4\,(p_{t+i} - p_{t+i-1})$ denoting the annualised one-quarter inflation rate.

Estimates of the model's parameters are taken from Coenen and Wieland (2005) and summarised in **Table 2**. Panel A of the table shows the estimated parameters of the alternative price and wage-setting specifications that form the supply side of the model. As indicated by the p-values for the tests of overidentifying restrictions that were imposed when estimating the staggered contracts specifications, neither Taylor nor Fuhrer-Moore-type contracts can be rejected on statistical grounds. Taylor-type contracts, however, are favoured somewhat by a higher p-value. Panel B shows the estimated parameters of the aggregate demand equation. The coefficients on the two lags of the output gap exhibit an accelerator pattern and the interest-rate sensitivity of aggregate demand is sizeable. For further details on the estimation of the model's alternative supply-side specifications and its demand side we refer the reader to Coenen and Wieland (2005).[12]

2.2 Implications for the Transmission of Monetary Policy

In principle, the estimated staggered contracts specifications, together with the estimated aggregate demand equation, would be sufficient to evaluate the stabilisation performance and robustness of alternative monetary policies. However, if we wish to know how the different contracting specifications would have affected the transmission of monetary policy historically we also need to specify an empirical benchmark. We could do so by estimating a policy reaction function which captures the historical path of the euro area short-term nominal interest rate.

Since (GDP-) weighted averages of European interest rates preceding the formation of European Monetary Union (EMU) in 1999 seem unlikely to be appropriate as a measure of the euro area-wide historical monetary policy stance, however, we resort to estimating a reaction function for the German interest rate (that we already used in estimating the aggregate demand equation discussed above; see Coenen and Wieland (2005) for details). After all, movements in German interest rates eventually had to be mirrored by the other European countries to the extent that they intended to maintain exchange-rate parities within the European Monetary System (EMS).[13]

The benchmark rule that we estimate is a forecast-based interest-rate rule which relates short-term nominal interest rates to variations of the one-year-ahead forecast of annual inflation in deviation from the policy-maker's inflation target π^* and the current output gap and also allows for interest-rate inertia, commonly referred to as the desired degree of policy "smoothing".[14] We estimate a generalised form of such a forward-looking rule allowing for up to two lags of the short-term nominal interest rate using quarterly German

[12] Of course, given that the estimation is based on aggregated historical euro area data (see Fagan, Henry and Mestre, 2005, for details), the reported estimates should be treated with some caution because of the differences across euro area member states in the pre-EMU period, as pointed out in the introduction.

[13] Clarida, Galí and Gertler (1998) also argue that German monetary policy had a strong influence on interest-rate policy in the U.K., France and Italy throughout the EMS period. More recently, Faust, Rogers and Wright (2001) estimate an interest-rate reaction function for Germany and use it to predict the interest rate the ECB would be setting, were it to behave like the Bundesbank.

[14] Work by Clarida and Gertler (1997) and Clarida, Galí and Gertler (1998) suggests that German interest-rate policy since 1979 is summarised quite well by such a forecast-based interest-rate rule.

data (standard errors in parentheses):

$$
\begin{aligned}
i_t^s \;=\; & \underset{(0.0271)}{1.0670}\, i_{t-1}^s - \underset{(0.0320)}{0.2764}\, i_{t-2}^s + (1 - 1.0670 + 0.2764)\,(\, r^* + \mathrm{E}_t[\tilde{\pi}_{t+4}]\,) \\
& \qquad\qquad + \underset{(0.0241)}{0.1778}\,(\, \mathrm{E}_t[\tilde{\pi}_{t+4}] - \pi^*\,) + \underset{(0.0169)}{0.0388}\, y_t + \epsilon_t^{i^s} .
\end{aligned}
$$

Here, i_t^s corresponds to the three-month money market rate, the annual inflation rate $\tilde{\pi}_t = p_t - p_{t-4}$ is the annual change in the log-level of the GDP deflator and the output-gap measure y_t has been constructed using quarterly real GDP data and annual output-gap estimates reported in OECD (2002). r^* again denotes the equilibrium real interest rate and π^* reflects the monetary policy-maker's inflation target. The term $\epsilon_t^{i^s}$ captures unexpected shocks to monetary policy. Motivated by earlier work of Clarida, Galí and Gertler (1998), the estimation period was chosen to start in the second quarter of 1979 with the formation of the European Monetary System; it ends in the fourth quarter of 1998, prior to the launch of the euro in January 1999.[15]

The estimated short-run response coefficients in the interest-rate rule capture the pattern of stabilisation policy during the 1980s and 1990s in Germany. Not surprisingly, the coefficient on the one-year-ahead inflation forecast is sizeable, implying a long-run coefficient of about 1.85. This ensures determinacy and stability of the rational expectations equilibrium, when solving the model under either of the wage contracting specifications.[16] The coefficient on the current output gap is a good bit smaller but positive; and the estimated degree of interest-rate smoothing turns out to be relatively high.[17]

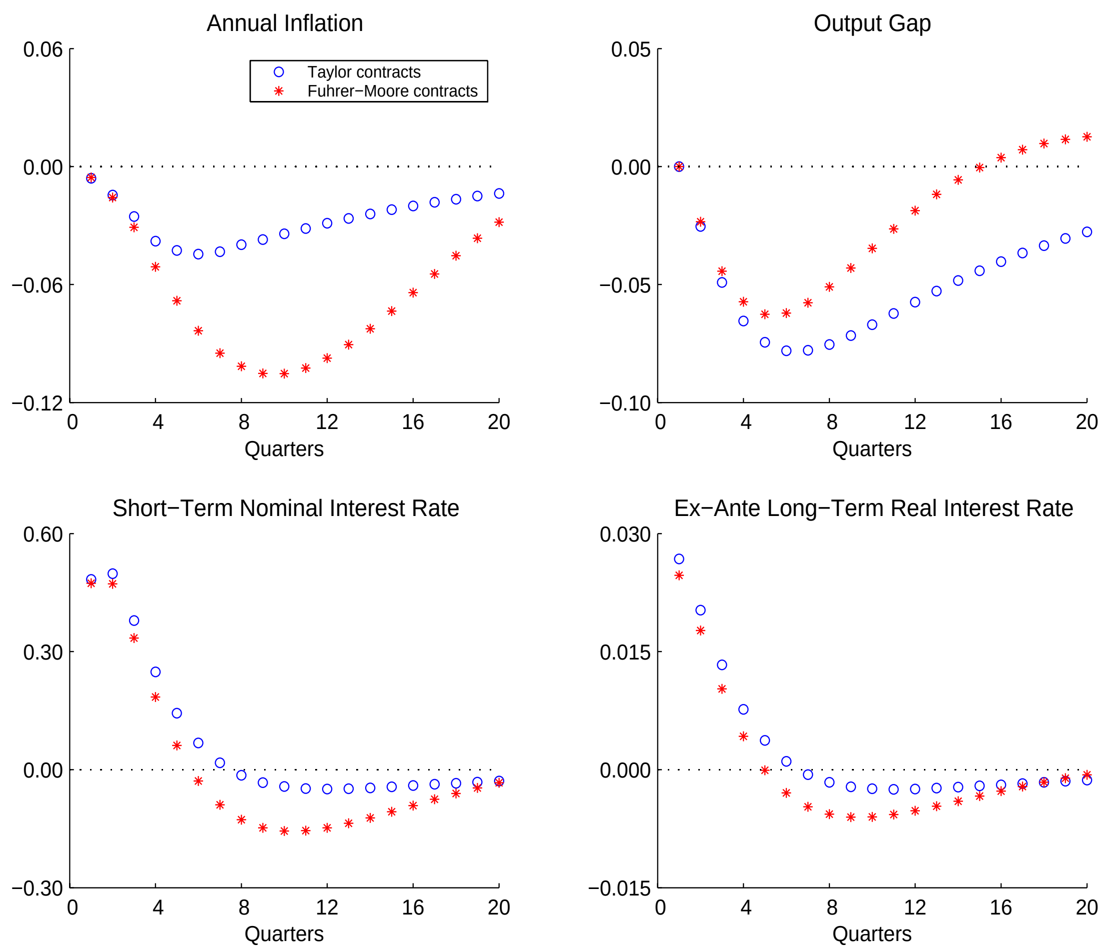
In the deterministic steady state of the model the output gap is zero and the short-term real interest rate equals its equilibrium value r^*. Since the alternative staggered contracts

[15] The interest-rate rule has been estimated by the Generalised Method of Moments (GMM) using lags up to order three of the interest rate, one-quarter inflation and the output gap as instruments. In addition, the current value and lags up to order two of the ratio of government expenditure to potential output have been used to account for demand pressures in the aftermath of German unification which, at least in part, reflect the consequences of increased government spending and transfers.

[16] See Woodford (2000, 2003) for a detailed discussion of the conditions regarding the size of the interest-rate response coefficient on current or expected inflation in order to guarantee uniqueness of the rational expectations equilibrium in a standard New-Keynesian sticky-price model. Extensions of these analytical results to models with a richer structure can be found, for example, in Batini, Levine and Pearlman (2004) and de Fiore and Liu (2005).

[17] The estimated intercept (not reported) reflects the Bundesbank's implicit inflation target π^* and the equilibrium real interest rate r^*.

Figure 1: Responses to an Unexpected Policy Tightening (50 Basis Points)



specifications do not impose any restriction on the steady-state inflation rate, the latter is determined by monetary policy alone and equals the policy-maker's target inflation rate π^* in the interest-rate rule.

Figure 1 provides a comparison of the effects of an unexpected tightening of monetary policy by 50 basis points under the two different wage contracting specifications. The upper two panels depict the responses of annual inflation and the output gap, while the lower two panels show the responses of the short-term nominal interest rate and the ex-ante long-term real interest rate (all variables expressed in percent). The circles refer to the responses under Taylor's wage contracting specification, while the asterisks correspond to the responses under the specification due to Fuhrer and Moore. Both the equilibrium real interest rate and the policy-maker's inflation target have been normalised to zero.

Qualitatively, the tightening of policy has the same consequences under the two wage contracting specifications. As the nominal interest rate rises unexpectedly, demand falls short of potential and inflation falls below target, with the dynamic adjustment towards the steady state being drawn out lastingly. Quantitatively, however, the responses exhibit some noticeable differences. Obviously, under Fuhrer-Moore-type contracts the disinflation effect is fairly large, with the peak effect on inflation being noticeably delayed relative to that on output. By contrast, the fall in inflation under Taylor-type contracts is rather contained and the peak effects on inflation and output occur virtually at the same point in time. These differences reflect that, under Fuhrer-Moore contracts, expectations regarding future inflation are more sensitive to excess demand and evolve in a much more persistent way, as discussed in more detail in Coenen and Wieland (2005). Thus, with the nominal interest rate being set in response to model-consistent forecasts of future inflation, the empirical benchmark rule prescribes to lower the nominal interest rate under Fuhrer-Moore contracts more vigorously when adjusting towards the steady state. As a result, ex-ante long-term real interest rates under Fuhrer-Moore contracts happen to be lastingly lower, inducing a less pronounced decline in aggregate demand.

Based on the documented pattern of the dynamic responses to an unexpected policy tightening, we summarise that a given interest-rate rule may perform quite differently in terms of inflation versus output stabilisation, depending on the particular type of staggered contracts. Hence, it is evident why monetary policy-makers should be concerned about the model of inflation determination when designing interest-rate policies.

3 Evaluating the Performance of Interest-Rate Rules

We now proceed to describe the methodology which we will use to evaluate the stabilisation performance of alternative monetary policies in the presence of uncertainty about the true model of inflation determination. Our starting point is an evaluation of simple interest-rate rules which respond to outcomes or forecasts of annual inflation and the output gap and allow for inertia due to dependence on the lagged short-term nominal interest rate.

3.1 The Methodology

Following the approach in LWW (2003), we consider a three-parameter family of simple interest-rate rules,

$$i_t^s = \rho\, i_{t-1}^s + (1-\rho)\,(\, r^* + \mathrm{E}_t\,[\,\tilde{\pi}_{t+\theta}\,]\,) + \alpha\, \mathrm{E}_t\,[\,\tilde{\pi}_{t+\theta} - \pi^*\,] + \beta\, \mathrm{E}_t\,[\,y_{t+\kappa}\,]\,,$$

where again i_t^s denotes the short-term nominal interest rate, r^* is the equilibrium real interest rate, $\tilde{\pi}_t = p_t - p_{t-4}$ is the annual inflation rate, π^* denotes the inflation target, and y_t is the output gap. Under rational expectations, the operator $\mathrm{E}_t[\,\cdot\,]$ indicates the model-consistent forecast of a particular variable, using information available in period t. The integer parameters θ and κ denote the length of the forecast horizons for inflation and the output gap, respectively. This specification accommodates both forecast-based rules (with forecast horizons $\theta, \kappa > 0$) as well as outcome-based rules ($\theta = \kappa = 0$) and simplifies to the one proposed by Taylor (1993b) if $\theta = \kappa = 0$, $\rho = 0$ and $\alpha = \beta = 0.5$.[18] For fixed inflation and output-gap forecast horizons θ and κ, the above family of interest-rate rules is defined by the response coefficients ρ, α and β. The coefficients α and β represent the policy-maker's instantaneous reaction to inflation in deviation from target and the output gap, respectively, while ρ determines the inertia of the interest-rate response, that is, the desired degree of policy "smoothing".

In our evaluation of the stabilisation performance of variants of the above family of policy rules, we assume that the monetary policy-maker has a standard loss function equal to the weighted sum of the unconditional variances of inflation, the output gap and changes in the short-term nominal interest rate,

$$\mathcal{L} = \mathrm{Var}[\,\pi_t\,] + \lambda\, \mathrm{Var}[\,y_t\,] + \mu\, \mathrm{Var}[\,\Delta i_t^s\,].$$

[18] In the special case with $\rho = 1$, the rule represents a first-difference rule, a class of rules which LWW (2003) advocate as being robust when examining the performance of simple interest-rate rules across a set of distinct rational expectations models of the U.S. economy. Orphanides and Williams (2002) emphasise that first-difference rules are also robust to misperceptions about the equilibrium real interest rate r^*.

Here, inflation is measured by the annualised one-quarter inflation rate, $\pi_t = 4\,(p_t - p_{t-1})$. The weight $\lambda \geq 0$ refers to the policy-maker's preference for reducing output variability relative to inflation variability, and the weight $\mu \geq 0$ on the variability of changes in the short-term nominal interest rate, $\Delta i_t^s = i_t^s - i_{t-1}^s$, reflects a desire to avoid undue fluctuations in the nominal interest rate itself. Establishing this loss function is consistent with the assumption that the policy-maker aims at stabilising inflation around the inflation target π^* and actual output around potential, with the concern regarding excessive interest-rate variability justified by financial stability considerations or the risk of hitting the zero-interest-rate bound.[19,20]

For fixed inflation and output-gap forecast horizons θ and κ, the family of interest-rate rules defined above is optimised for each of the two alternative models of inflation determination by minimising the policy-maker's loss function $\mathcal{L}$ with respect to the coefficients ρ, α and β.[21] In this context, in order to evaluate the policy-maker's loss function, we repeatedly need to compute the unconditional variances of the model's endogenous variables for a particular interest-rate rule. In preparation for these computations, we first identify the series of historical structural shocks that would be consistent with the alternative contracting specifications under rational expectations with the estimated benchmark for historical monetary policy being imposed.[22] Based on the covariance matrix of the structural shocks, it is then possible to calculate the unconditional covariance matrix of the endogenous variables for a given interest-rate rule by applying standard methods to the reduced-form solution of

[19]For an explicit derivation of the policy-maker's loss function $\mathcal{L}$ from quadratic intertemporal preferences the reader is referred to Rudebusch and Svensson (1999). In Svensson's (1999) terminology, the case of $\lambda = \mu = 0$ corresponds to a regime of "strict" inflation targeting, while "flexible" inflation targeting is characterised by $\lambda, \mu > 0$.

[20]It is recognised that it would be beneficial to use a welfare criterion derived as an approximation of the representative agent's utility function (see for example Rotemberg and Woodford, 1997). The weights in this approximate welfare criterion would be functions of the parameters of the structural model itself. However, to the extent that the models used in this paper are lacking full micro-foundations, a well-defined welfare criterion does not exist.

[21]We employ a gradient-based numerical optimisation algorithm to determine the coefficients of the interest-rate rule that minimise the loss function. For any particular set of coefficients we check whether the model has a unique linear rational expectations solution.

[22]The historical structural shocks differ from the single-equation estimation residuals, because expectations of future variables are computed to be consistent with the complete model, including the empirical benchmark for monetary policy discussed in Section 2.2. The relevant sample period is 1979Q2 to 1998Q4, given the estimation period for the benchmark rule.

the model including that rule.

In the subsequent analysis, we will consider four alternative values for the relative weight on output-gap variability in the loss function, namely $\lambda = 0,\ 1/2\,,1$ and 2. Regarding the weight on the variability of interest-rate changes in the loss function, we concentrate the analysis on a fixed value of $\mu = 1$. This weight is relatively high, but avoids extreme and counterfactual interest-rate variability under the optimised interest-rate rules.[23]

3.2 Optimised Benchmark Rules

As a benchmark for evaluating the robustness of optimised interest-rate rules, **Table 3** reports the optimised response coefficients for a collection of outcome and forecast-based rules under each of the two alternative staggered contracts models, together with an indication of their stabilisation performance. Regarding the choice of forecast-based rules, we consider three different combinations of forecast horizons: one-quarter-ahead and four-quarter-ahead inflation forecasts combined with the current output gap, as used in many theoretical and empirical studies in the literature; and four-quarter-ahead forecasts of both inflation and the output gap. The last combination is motivated by the pattern of the dynamic responses depicted in Figure 1 above which illustrates that a particular interest-rate rule may lead to quite distinct profiles for the time paths of both inflation and the output gap under the two alternative types of staggered contracts. As a result, choosing the forecast horizons for both inflation and the output gap may have important consequences for the stabilisation performance and robustness of interest-rate rules.

Table 3 shows that the optimised benchmark rules are characterised by a substantial degree of interest-rate smoothing under both types of staggered contracts and regardless of the policy-maker's preference for output stabilisation λ, as indicated by the high coefficient on the lagged interest rate ρ. Interestingly, with the forecast horizons θ and κ extending one

[23] In the working paper version of this study (see Coenen, 2003) it is shown that the results are fairly insensitive to the weight on interest-rate variability in the loss function. The working paper version also provides results for interest-rate rules which do not allow for a direct response to the output gap. Such rules have been used as a proxy for the decision-making frameworks in inflation-targeting countries where policy-makers are widely perceived as setting interest rates in response to deviations of short to medium-term inflation forecasts from the target rate (see, for example, Batini and Nelson, 2001). In these frameworks, information on the output gap is only used to the extent it helps to produce forecasts of future inflation.

Table 3: The Stabilisation Performance of Optimised Interest-Rate Rules

			Taylor contracts					Fuhrer-Moore contracts				
θ	κ	λ	ρ	α	β	$\mathcal{L}_{\text{T}}$	$\%\Delta\mathcal{L}_{\text{T}}$	ρ	α	β	$\mathcal{L}_{\text{FM}}$	$\%\Delta\mathcal{L}_{\text{FM}}$
0	0	0	0.97	0.21	0.06	1.98	2.29	0.86	0.46	0.41	4.30	1.98
		1/2	0.86	0.03	0.40	3.02	3.62	0.85	0.41	0.53	5.54	1.80
		1	0.85	0.04	0.57	3.68	3.35	0.83	0.39	0.62	6.60	2.01
		2	0.85	0.06	0.78	4.83	3.42	0.82	0.36	0.78	8.40	2.56
1	0	0	0.98	0.23	0.05	2.00	2.90	0.89	0.45	0.35	4.30	2.16
		1/2	0.86	0.03	0.40	3.03	3.83	0.87	0.40	0.46	5.55	1.94
		1	0.85	0.04	0.56	3.68	3.36	0.86	0.38	0.55	6.61	2.19
		2	0.84	0.06	0.78	4.82	3.27	0.84	0.35	0.70	8.42	2.85
4	0	0	1.27	1.32	-0.09	2.05	5.47	0.99	0.77	0.20	4.42	4.96
		1/2	0.86	0.19	0.40	3.05	4.48	0.96	0.65	0.30	5.66	3.99
		1	0.84	0.11	0.57	3.68	3.38	0.93	0.58	0.39	6.73	4.02
		2	0.83	0.07	0.78	4.80	2.78	0.91	0.52	0.54	8.56	4.58
4	4	0	1.21	1.20	-0.09	2.05	5.58	1.07	1.00	0.37	4.42	4.92
		1/2	0.98	0.37	0.72	3.05	4.65	1.06	0.96	0.62	5.65	3.86
		1	1.00	0.33	1.21	3.70	3.80	1.07	0.96	0.87	6.71	3.82
		2	1.04	0.33	2.01	4.83	3.47	1.08	1.00	1.37	8.54	4.30

Note: For each choice of the inflation and output-gap forecast horizons (θ and κ), for each preference parameter (λ) and for each contracting specification (m), this table indicates the optimised interest-rate response coefficients (ρ, α and β), the value of the policy-maker's loss function ($\mathcal{L}_m$) and the percentage-point difference of the latter from the loss under the fully optimal policy ($\%\Delta\mathcal{L}_m$).

year into the future, the magnitude of ρ tends to exceed unity, a feature which is commonly referred to as "super-inertia" in the interest rate.[24] Not surprisingly, as the weight on output stabilisation increases, the response coefficient on the output gap β rises while the response coefficient on the inflation gap α falls, albeit less dramatically for Fuhrer-Moore-type contracts. Moreover, under Fuhrer-Moore-type contracts the coefficient on the inflation

[24]Rules with $\rho > 1$ might seem implausible at first sight, because commitment to such a rule implies a commitment to continue raising interest rates at an explosive rate, if inflation is ever even temporarily above target. However, in a rational-expectations equilibrium, this never will happen since any temporary increase in inflation will be followed by subsequent undershooting of the target (see Woodford, 2003, for further discussion).

gap is typically a good bit larger than under Taylor-type contracts. This reflects the fact that the inflation process is much harder to control under Fuhrer-Moore-type contracts and, consequently, the policy-maker has to respond more aggressively to any incipient sign of rising inflation.

For each of the two contracting models, $m = \mathrm{T}, \mathrm{FM}$, the stabilisation performance of a given optimised interest-rate rule is measured by the implied value of the policy-maker's loss function, $\mathcal{L}_m$, and alternatively, in relative terms, as the percentage-point difference of latter from the loss under the fully optimal policy under commitment for that particular model, $\%\Delta\mathcal{L}_m$.[25] Evidently, with the same weight on interest-rate variability, the values of the loss function obtained for Fuhrer-Moore-type contracts are quite a bit larger than those obtained for Taylor-type contracts. At the same time, we observe that, regardless of the type of contracting specification, the relative stabilisation performance of monetary policy is barely affected when the policy-maker is constrained to follow an optimised simple interest-rate rule rather than the fully optimal policy under commitment. Under both Taylor and Fuhrer-Moore-type contracts the increase in the value of the policy-maker's loss function is always smaller than 6 percent.[26]

Interestingly, there is no stabilisation gain from following forecast-based as opposed to outcome-based rules. This can be attributed to the fact that current inflation and the current output gap are effective summary statistics of any risks to future inflation, given the relatively simple structure of the models under consideration. Of course, for a model with a sufficiently rich structure, it may well be that forecast-based rules outperform simple outcome-based rules since forecasts, due to their information-encompassing nature, eventually incorporate information about risks to inflation from a possibly larger set of determinants or help to better attune monetary policy to lags in the transmission mechanism

[25]See Finan and Tetlow (1999) for details on computing the fully optimal policy under commitment for possibly large-scale rational expectations models using AIM.

[26]The historical benchmark rule (i.e., the estimated interest-rate rule with $\theta = 4$ and $\kappa = 0$; see Section 2.2) yields less favourable outcomes. With a moderate weight of $\lambda = 1/2$ on output variability, for example, the value of the loss function under Taylor (Fuhrer-Moore) contracts exceeds the loss under the fully optimal policy by 43 (78) percent, possibly reflecting a rather weak response to the output gap in the historical benchmark rule.

(see Batini and Nelson, 2001).[27]

Based on these results, one might conclude that relying on simple interest-rate rules which are optimised for a particular model of the inflation process does not compromise the overall stabilisation performance of monetary policy and, hence, seems innocuous. However, our analysis thus far has assumed that the monetary policy-maker knows the "true" model of inflation determination when designing and implementing simple interest-rate rules. As we will see below, the stabilisation performance of such rules can deteriorate dramatically, if this assumption is invalid.

4 The Robustness of Optimised Interest-Rate Rules

In the previous section it was assumed that the policy-maker knows the "true" model of inflation determination as represented by either Taylor or Fuhrer-Moore-type contracts. For each of these two contracting specifications, we designed optimal interest-rate rules which performed remarkably well in stabilising inflation and the output gap for given preferences of the policy-maker. In the case that the optimised rules prescribed to set the interest rate in response to forecasts of future inflation or the output gap, these forecasts happened to be consistent with the structure of the model.

In the presence of uncertainty about the true model of the inflation process, however, two distinct sources of making policy mistakes can be identified. First, when designing outcome or forecast-based interest-rate rules, the policy-maker may mistakenly rely on the "false" model of the inflation process. And second, when implementing a given forecast-based rule, the policy-maker may also rely on forecasts which are based on the false model by mistake. We will refer to these two sources of making policy mistakes as uncertainty about the rule-generating model and the forecast-generating model, respectively. Of course, for forecast-based rules the second type of mistake is most likely to occur in conjunction with the first and, thus, we shall consider them in combination as well.

In the following we shall assess the robustness of the optimised benchmark rules reported

[27] In fact, in the sensitivity analysis reported in Coenen (2003), it is shown that inflation forecast-based rules which do not allow for a direct response to the output gap yield improved stabilisation outcomes relative to outcome-based rules, once the forecast horizon is extended beyond one year into the future.

in Table 3 above when there is uncertainty about the true model of inflation determination by evaluating the potential costs associated with the two distinct sources of making policy mistakes. For the two alternative models of the inflation process, $m = \mathrm{T}, \mathrm{FM}$, these costs are measured as the percentage-point difference of the value of the policy-maker's loss function that is yielded under the rule optimised for the false model, $n \neq m$, from the loss that would occur under the benchmark rule for the true model, $\%\Delta\mathcal{L}_m$.

Our findings regarding the robustness of the optimised benchmark rules are summarised in **Table 4**. Starting with the outcome-based rules in the upper-left panel of the table ($\theta = \kappa = 0$), we observe that the stabilisation performance of these rules deteriorates noticeably if they are evaluated in a model incorporating a markedly different degree of inflation persistence. The performance deteriorates most severely if the policy-maker puts zero weight on output stabilisation ($\lambda = 0$). Evidently, if outcome-based rules that are optimised under the assumption that the degree of inflation persistence is high (i.e., under Fuhrer-Moore-type contracts) are implemented in the low-persistence model (i.e., under Taylor-type contracts), the value of the policy-maker's loss function never increases by more than 21 percent. In contrast, employing outcome-based rules that are optimised under Taylor-type contracts within a model incorporating Fuhrer-Moore-type contracts results in distortions that are significantly larger. In the extreme case, the value of the loss function is found to increase by about 225 percent; that is, the relative increase in the loss under Fuhrer-Moore contracts is about ten times larger than under Taylor contracts.[28]

We next turn to the forecast-based interest-rate rules in the three lower panels of Table 4 ($\theta > 0, \kappa \geq 0$). Here, we consider three alternative assumptions regarding the formation of forecasts. First, we assume that the policy-maker uses forecasts based on the correct model of the inflation process, $\mathrm{E}_t^m[\,\cdot\,]$. In this case, the forecasts are *model-consistent*, even though the implemented rule itself is poorly designed by relying on the false model of

[28] Since certainty equivalence does not hold for optimised simple interest-rate rules, we also considered separately the case when there is uncertainty about the variance-covariance matrix of the shock processes alone in order to assess the consequences of deviating from certainty equivalence. While important from a conceptual point of view, it was found that the quantitative effects are fairly limited. This largely reflects the fact that the historical variance-covariance matrices under Taylor and Fuhrer-Moore-type contracts are not too different.

Table 4: The Robustness of Optimised Interest-Rate Rules

			Consistent forecasts		Inconsistent forecasts		Pooled forecasts	
θ	κ	λ	$\%\Delta\mathcal{L}_{\mathrm{T}}$	$\%\Delta\mathcal{L}_{\mathrm{FM}}$	$\%\Delta\mathcal{L}_{\mathrm{T}}$	$\%\Delta\mathcal{L}_{\mathrm{FM}}$	$\%\Delta\mathcal{L}_{\mathrm{T}}$	$\%\Delta\mathcal{L}_{\mathrm{FM}}$
0	0	0	20.96	224.30				
		1/2	8.04	70.01				
		1	7.83	83.02				
		2	7.40	86.10				
1	0	0	18.92	154.97	23.14	229.83	20.87	186.35
		1/2	6.95	82.63	10.22	ME	8.48	ME
		1	7.05	99.67	10.06	ME	8.47	ME
		2	6.86	103.44	9.53	ME	8.12	ME
4	0	0	8.93	58.94	33.23	558.68	16.44	88.10
		1/2	1.99	27.45	18.82	ME	7.44	ME
		1	3.09	47.06	18.10	ME	8.11	ME
		2	3.45	63.86	16.77	ME	8.04	ME
4	4	0	9.70	44.28	25.29	615.45	13.88	79.17
		1/2	1.49	20.41	18.92	ME	7.49	59.60
		1	2.22	30.83	17.74	ME	7.76	93.18
		2	2.62	34.95	15.93	ME	7.50	115.56

Note: For each choice of the inflation and output-gap forecast horizons (θ and κ), for each preference parameter (λ) and for each contracting specification (m), this table indicates the percentage-point difference of the policy-maker's loss function under the rule optimised for the "false" model from the loss under the rule optimised for the "true" model ($\%\Delta\mathcal{L}_m$). Each of the forecast-based rules is implemented using consistent, inconsistent and pooled forecasts, respectively. The notation "ME" indicates that the implemented rule yields multiple equilibria.

the inflation process. Conceivably, this corresponds to a situation where the policy-maker employs two different models for producing forecasts and setting interest rates, respectively. As shown in the table, the implementation of forecast-based rules which are optimised under the wrong assumption regarding the degree of structural inflation persistence results in a quite pronounced deterioration in the stabilisation performance of monetary policy, as was documented for outcome-based rules above. However, the deterioration in performance is found to decline for at least moderate forecast horizons, with rules responding to the one-year-ahead forecast of inflation even outperforming outcome-based rules. For the model with Taylor-type contracts, for example, the maximum increase in the value of the loss function amounts to more than 20 percent under outcome-based rules, while the loss rises by less than 10 percent under rules prescribing a response to the one-year-ahead inflation forecast. Obviously, regarding the degree of sensitivity of the two distinct contracting specifications, the percentage-point increase in the value of the loss function for the model with Fuhrer-Moore-type contracts is again larger by a factor of about ten.

Second, we assume that the policy-maker not only follows a poorly designed interest-rate rule but also relies on *model-inconsistent* forecasts when implementing that particular rule, with the model-inconsistent forecasts, $\mathrm{E}_t^n[\,\cdot\,]$, also based on the wrong model of the inflation process, $n \neq m$.[29] Hence, the policy-maker happens to rely on an incorrect rule-generating model and an incorrect forecast-generating model at the same time. By comparing the implied outcomes with those obtained under the correctly implemented benchmark rule, we observe that the deterioration in performance is still contained if forecast-based rules that were erroneously designed for Fuhrer-Moore contracts are implemented in the model with Taylor contracts using Fuhrer-Moore-based forecasts by mistake. In contrast, for the model incorporating Fuhrer-Moore contracts, implementing wrongly designed rules with inconsistent forecasts may result in a dramatic deterioration of the ability of monetary policy to stabilise the economy with the relative increase in the value of the loss function inflated by a factor of ten. Even worse, in most cases the solution of the model turns out to be indeterminate, with non-fundamental shocks eventually contributing to the variance of economic fluctuations themselves.

Finally, we assess the stabilisation performance of optimised forecast-based rules if the policy-maker resorts to *pooled* forecasts when implementing these rules. Pooling of forecasts from different models is a practice well-known from the time-series literature and aims at making forecasts more reliable in the presence of model misspecification (see, e.g., Hendry and Clements, 2002). In the present context, forecast pooling is achieved by forming a (sim-

[29] Specifically, the model-inconsistent forecasts $\mathrm{E}_t^n[\,\cdot\,]$ are computed as a linear function of the relevant state variables of the wrong model n using AIM, which is then incorporated as the forecast-generating function in the model in which the optimised rule is to be evaluated.

ple) weighted average of the individual forecasts obtained under the two alternative wage contracting specifications, $\bar{\mathrm{E}}_t[\,\cdot\,] = 1/2\,(\,\mathrm{E}_t^{\mathrm{T}}[\,\cdot\,] + \mathrm{E}_t^{\mathrm{FM}}[\,\cdot\,]\,)$.[30] In this case, the percentage-point increase in the policy-maker's loss function is typically found to be markedly lower when compared with the percentage-point increase in the loss function resulting from the use of inconsistent forecasts. The relative improvement is found to be particularly large for the model with Fuhrer-Moore-type contracts, at least to the extent that using pooled forecasts yields a unique rational expectations solution. Hence, as far as the distortions arising from the use of the wrong forecasting model are concerned, pooling of forecasts rather than relying on any single model's forecast, which can be largely destabilising under incorrect assumptions regarding the degree of inflation persistence, may serve as a simple means of making forward-looking monetary policies more robust.

By showing the dynamic responses of annual inflation, the output gap and the ex-ante long-term real interest rate to a contract wage shock, **Figure 2** provides insights into the reasons why interest-rate rules that are designed for a regime with a low degree of structural inflation persistence (i.e., for a regime with Taylor-type contracts) result in a rather poor stabilisation performance of monetary policy if the degree of inflation persistence is actually high (i.e., in a regime with Fuhrer-Moore-type contracts). To this end, the figure depicts the dynamic responses under two different scenarios for the case $\theta = 4$, $\kappa = 0$ and $\lambda = 1/2$ (i.e., for an inflation-forecast-based rule with a moderate weight on output stabilisation; all variables are expressed in percent).[31, 32] The first scenario is based on the assumption that monetary policy follows the optimised benchmark rule using model-consistent forecasts (the responses are indicated by circles), and the second scenario assumes that interest rates are set according to the rule optimised for the wrong model, again using model-consistent forecasts (the responses are indicated by asterisks).

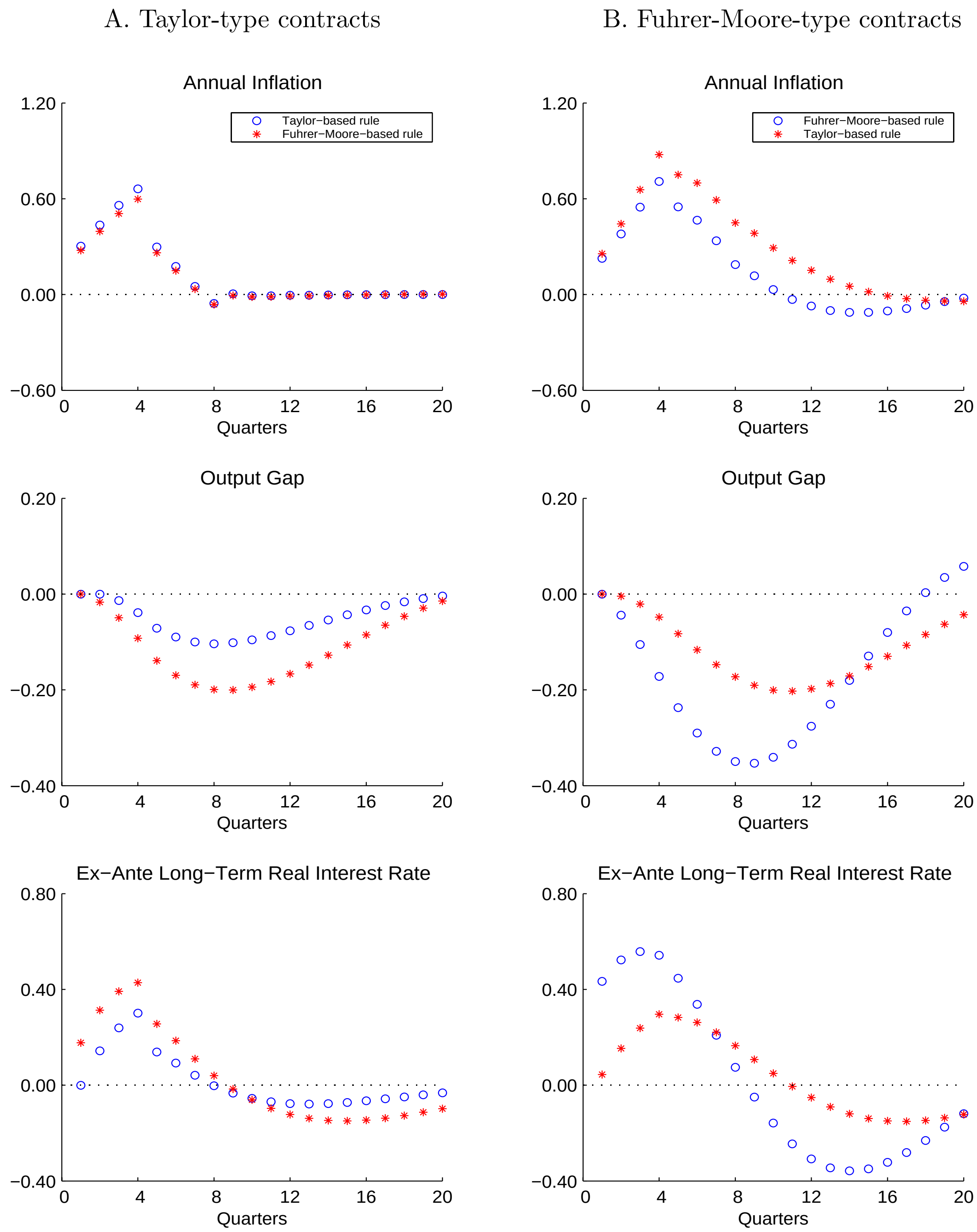
As is evident from comparing the responses of annual inflation across the two contracting

[30]The pooled forecast $\bar{\mathrm{E}}_t[\,\cdot\,]$ is computed as the average of the two linear forecast-generating functions that are implied by the two alternative models.

[31]For each of the two contracting specifications, the size of the contract wage shock has been set equal to the standard deviation of the historical shocks obtained under the estimated interest-rate rule (see Section 2.2).

[32]For other combinations of the forecast horizons θ and κ or other values of the preference parameter λ the results are qualitatively similar.

Figure 2: Responses to a Contract Wage Shock under Alternative Interest-Rate Rules



specifications (see columns A and B in Figure 2, respectively), departing from the optimised benchmark rule has a much larger effect on the responses of inflation under Fuhrer-Moore-type contracts than under Taylor-type contracts. The reason is that a regime characterised by a relatively high degree of structural inflation persistence calls for a rather aggressive interest-rate response to inflation (as shown in Table 3 above). Thus, a contract wage shock will induce an even stronger and more persistent rise in inflation if the coefficient on inflation happens to be sub-optimally small. Conversely, while a small coefficient on inflation works best for a low-persistence regime, there is not much harm in choosing a larger coefficient: low inflation persistence means that short-term real interest rates can drop relatively quickly, so that a more aggressive response to inflation does not have very different effects on the long-term real interest rate or the output gap.

Implementing the interest-rate rule designed for Fuhrer-Moore-type contracts in the model with Taylor-type contracts using Fuhrer-Moore-based forecasts by mistake (not shown in Figure 2), results in a noticeably stronger increase in the ex-ante long-term real rate. The reason is that the nominal interest rate is raised too strongly in response to the inconsistent Fuhrer-Moore-based inflation forecast, which largely overpredicts the strength and persistence of the inflationary consequences of the contract wage shock. Therefore, the implied fluctuations in output are quite a bit larger than those obtained when implementing the Fuhrer-Moore-based rule using consistent forecasts, with the fluctuations in inflation yet again being hardly affected though. By contrast, if the rule designed for Taylor-type contracts is implemented in the Fuhrer-Moore model using Taylor-based forecasts, the ex-ante long-term real interest rate tends to fall below zero in response to the contract-wage shock, yielding indeterminate equilibrium outcomes.

Overall, these results indicate that a cautious policy-maker who tries to avoid very poor stabilisation outcomes is well-advised to design and implement monetary policies under the assumption that the degree of inflation persistence is high, as long as there is considerable uncertainty regarding the true characteristics of the inflation process.

5 Designing Robust Interest-Rate Rules

Having documented the potential lack of robustness of optimised interest-rate rules which rely on the assumption that a particular type of staggered contracts specification correctly represents the inflation process, we finally proceed to identify the operating characteristics of simple interest-rate rules which are likely to perform reasonably well under both types of staggered contracts.

In search of such robust rules we follow the Bayesian approach outlined in LWW (1999, 2003) and optimise the response coefficients of the three-parameter family of interest-rate rules defined in Section 3.1 across the two contracting models simultaneously by minimising a weighted average of the associated loss functions,

$$\bar{\mathcal{L}} \;=\; \sum_{m\in\mathcal{M}} \omega_m \, \mathcal{L}_m,$$

where ω_m denotes the weight attached to any given model $m \in \mathcal{M} = \{\, \mathrm{T}, \mathrm{FM} \,\}$ with $\omega_m \geq 0$ and $\sum \omega_m = 1$. For $\omega_m = 0.5$, the average loss corresponds to the policy-maker's expected loss function when he has uniform prior beliefs as to which model m is a plausible representation of the inflation process.

Table 5 reports the response coefficients of the *Bayesian* robust interest-rate rules that are optimised across the two contracting models simultaneously assuming uniform prior beliefs and indicates the stabilisation performance of these rules yielded in the individual models. Here, performance is measured as the contributions of the individual models to the value of the policy-maker's loss function, $\mathcal{L}_m$, and, alternatively, as the percentage-point difference of these contributions from the losses under the fully optimal policies for the individual models, $\%\Delta\mathcal{L}_m$.

As shown in Table 5, the pattern of the response coefficients of the Bayesian robust rules is quite similar to the pattern of the optimised response coefficients that were obtained for the model with Fuhrer-Moore-type contracts separately (see Table 3 above). In particular, the short-run response coefficients, notably those on inflation, are fairly large and the degree of interest-rate inertia is relatively high.[33] This decisive role of Fuhrer-Moore-type contracts

[33]This is consistent with the findings in a study by Söderström (2002) who shows, by applying formal

Table 5: The Performance of Bayesian Robust Interest-Rate Rules

						Taylor		Fuhrer-Moore	
θ	κ	λ	ρ	α	β	$\mathcal{L}_{\mathrm{T}}$	$\%\Delta\mathcal{L}_{\mathrm{T}}$	$\mathcal{L}_{\mathrm{FM}}$	$\%\Delta\mathcal{L}_{\mathrm{FM}}$
0	0	0	0.87	0.38	0.34	2.29	18.17	4.34	3.07
		1/2	0.86	0.33	0.48	3.18	9.06	5.58	2.44
		1	0.85	0.31	0.59	3.88	8.82	6.63	2.55
		2	0.84	0.30	0.76	5.07	8.62	8.44	3.03
1	0	0	0.90	0.39	0.29	2.29	17.59	4.34	3.11
		1/2	0.88	0.34	0.43	3.17	8.86	5.57	2.43
		1	0.86	0.32	0.54	3.87	8.61	6.64	2.63
		2	0.85	0.31	0.71	5.05	8.31	8.45	3.25
4	0	0	0.99	0.78	0.13	2.17	12.09	4.44	5.52
		1/2	0.94	0.63	0.31	3.09	6.03	5.67	4.11
		1	0.92	0.58	0.43	3.76	5.50	6.74	4.27
		2	0.89	0.53	0.61	4.89	4.77	8.59	4.93
4	4	0	1.03	0.91	0.21	2.18	12.56	4.45	5.59
		1/2	1.05	0.92	0.61	3.09	5.93	5.66	3.93
		1	1.06	0.95	0.94	3.76	5.60	6.72	3.94
		2	1.08	1.04	1.57	4.92	5.35	8.56	4.49

Note: For each choice of the inflation and output-gap forecast horizons (θ and κ) and for each preference parameter (λ), this table indicates the jointly optimised interest-rate response coefficients (ρ, α and β), the contribution of each individual model (m) to the policy-maker's loss function ($\mathcal{L}_m$) and the percentage-point difference of this contribution from the loss under the fully optimal policy ($\%\Delta\mathcal{L}_m$).

in shaping the operating characteristics of Bayesian robust rules is explained by the fact that inflation and output-gap dynamics in the model with Fuhrer-Moore contracts are much more sensitive to small deviations from the optimised response coefficients, as was illustrated in Figure 2 above. As a result, the loss function under Fuhrer-Moore contracts exhibits a stronger curvature with respect to sub-optimal variations in the response coefficients. And hence, taking into account its relatively high baseline level, the loss function under

Bayesian analysis to a simplified version of the Rudebusch-Svensson (1999) model, that heightened responsiveness is optimal when there is uncertainty about the parameters characterising the degree of inflation persistence. The intuition is that a more aggressive response reduces uncertainty regarding the future path of inflation.

Fuhrer-Moore contracts dominates the behaviour of the weighted loss function $\bar{\mathcal{L}}$. Given its strong influence in determining the operating characteristics of Bayesian robust rules, the loss function under Fuhrer-Moore contracts increases only slightly when implementing these rules, while the increase in the loss function under Taylor contracts is somewhat more pronounced, in particular if the weight on output stabilisation is low. Obviously, this contrasts favourably with the lack of robustness of rules that were optimised for the two alternative models of the inflation process separately.[34]

Table 6 indicates the stabilisation performance of the forecast-based variants of the Bayesian robust rules when these rules are implemented using either model-inconsistent or pooled forecasts. Here, the value of the policy-maker's loss function under the Bayesian robust rule that is implemented with model-consistent forecasts (see Table 5 above) is used as the benchmark for comparison. Overall, the distortions due to the use of model-inconsistent forecasts are noticeable, in particular if the forecast horizon extends further into the future. Nevertheless, the outcomes compare favourably with those reported in Table 4; that is, when implementing rules that are optimised for the wrong model using inconsistent forecasts. Notice, however, that using forecasts based on Taylor-type contracts still yields indeterminate equilibria in the model with Fuhrer-Moore-type contracts if the policy-maker puts either a very high or a very low weight on output stabilisation. Yet, the results documented in Table 6 clearly confirm that pooling of forecasts can again help to alleviate the distortions in the stabilisation performance of forecast-based rules that arise from using the wrong forecasting model. Importantly, in this case none of the Bayesian robust rules yields indeterminate equilibria.

[34]The model with Fuhrer-Moore contracts gives equal weight to forward and backward-looking elements in determining inflation. Thus, in principle it may still underestimate the degree of persistence prevailing in reality. Nevertheless, the finding that the more persistent model of the inflation process influences the characteristics of robust policies decisively ought to extend to models that feature an even higher degree of persistence. For example, in a related study by Adalid, Coenen, McAdam and Siviero (2005), which utilises a set of four distinct models of the euro area that differ considerably in terms of size, degree of aggregation and relevance of forward-looking elements, it is found that entirely or at least predominantly backward-looking models call for even more aggressive interest-rate policies, although for less interest-rate inertia. Entirely or at least predominantly backward-looking models of the inflation process, however, may not be a reasonable representation of euro area inflation, as argued in the introduction of this paper. Moreover, estimates of the hybrid New-Keynesian Phillips curve (see, e.g., Galí et al., 2001) tend to suggest that the weight on backward-looking elements implied by Fuhrer-Moore contracts is rather on the high side.

Table 6: The Performance of Bayesian Robust Rules if the Forecasting Model Is Incorrect

			Inconsistent forecasts		Pooled forecasts	
θ	κ	λ	$\%\Delta\mathcal{L}_{\mathrm{T}}$	$\%\Delta\mathcal{L}_{\mathrm{FM}}$	$\%\Delta\mathcal{L}_{\mathrm{T}}$	$\%\Delta\mathcal{L}_{\mathrm{FM}}$
1	0	0	2.83	1.76	1.31	0.69
		1/2	2.37	1.54	1.11	0.60
		1	2.26	1.54	1.07	0.60
		2	2.10	1.55	1.00	0.58
4	0	0	10.84	ME	7.42	12.62
		1/2	16.93	77.46	5.55	6.37
		1	15.64	100.55	5.34	6.98
		2	14.37	ME	5.02	8.17
4	4	0	22.89	116.66	7.30	10.86
		1/2	16.69	54.04	5.72	6.02
		1	15.09	55.66	5.39	6.10
		2	13.18	56.76	4.84	6.25

Note: For each choice of the inflation and output-gap forecast horizons (θ and κ), for each preference parameter (λ) and for each contracting specification (m), this table indicates the percentage-point difference of the policy-maker's loss function ($\%\Delta\mathcal{L}_m$) when the Bayesian robust forecast-based rule is implemented using either inconsistent or pooled forecasts from the loss under the Bayesian robust rule implemented with consistent forecasts. The notation "ME" indicates that the implemented rule yields multiple equilibria.

As is evident from Table 5, one notable feature of Bayesian robust rules is the rather high degree of interest-rate inertia, in particular if the interest rate is set in response to one-year-ahead inflation or output-gap forecasts. This raises the possibility that first-difference rules that relate changes in the interest rate to inflation and output-gap forecasts which do not extend too far into the future may already go a long way towards making interest-rate rules robust to markedly different degrees of inflation persistence.

In the light of this observation, **Table 7** summarises our findings regarding the stabilisation performance of a calibrated first-difference rule which relates the change in the short-term nominal interest rate to the one-year-ahead forecast of annual average inflation

Table 7: The Performance of a Calibrated Forecast-Based First-Difference Rule

	Consistent forecasts		Inconsistent forecasts		Pooled forecasts	
λ	$\%\Delta\mathcal{L}_{\mathrm{T}}^{(1)}$	$\%\Delta\mathcal{L}_{\mathrm{FM}}^{(1)}$	$\%\Delta\mathcal{L}_{\mathrm{T}}^{(2)}$	$\%\Delta\mathcal{L}_{\mathrm{FM}}^{(2)}$	$\%\Delta\mathcal{L}_{\mathrm{T}}^{(2)}$	$\%\Delta\mathcal{L}_{\mathrm{FM}}^{(2)}$
0	17.11	5.20	20.63	69.34	6.20	6.98
1/2	9.00	5.60	17.16	51.73	5.44	3.95
1	14.58	9.23	15.23	40.68	5.02	2.04
2	26.33	18.40	13.15	27.58	4.56	-0.21

Note: For each preference parameter (λ) and each contracting specification (m), this table indicates the percentage-point change in the policy-maker's loss function ($\%\Delta\mathcal{L}_m$) under the calibrated forecast-based first-difference rule. The first-difference rule is implemented using consistent, inconsistent and pooled forecasts, respectively. The superscript "(1)" indicates the comparison with the loss under the fully optimal policy, whereas the superscript "(2)" indicates the comparison with the loss under the first-difference rule implemented with consistent forecasts.

and the current output gap,

$$\Delta i_t^s \quad = \quad 0.75\,\mathrm{E}_t[\,\tilde{\pi}_{t+4} - \pi^*\,] + 0.25\,y_t,$$

with the response to the expected inflation gap chosen to be somewhat stronger than to the current output gap.

Evidently, as shown in Table 7, the calibrated first-difference rule performs remarkably well across the two models of inflation determination, in particular when the policy-maker puts a modest weight on output stabilisation. Also, the implementation of inconsistent forecasts always yields determinate solutions, with pooled forecasts yet again providing insurance against the adverse consequences of choosing the incorrect forecasting model.

6 Conclusions

We have examined the robustness of simple interest-rate rules to the markedly different degrees of inflation persistence that are induced by two distinct types of staggered contracts specifications within an estimated small-scale macroeconomic model of the euro area. Our central conclusion is that it may be very risky to rely too heavily on rules that are designed and implemented under the assumption that the degree of structural inflation persistence is low. These rules may result in very poor stabilisation outcomes if the inflation process turns out to be considerably more persistent in reality. In contrast, rules designed and implemented under the assumption that the degree of inflation persistence is relatively high also perform reasonably well if inflation persistence is actually low. The reason for this asymmetry in behaviour is that inflation dynamics are much more sensitive to even small deviations from the optimal response coefficients if the degree of inflation persistence is high. Hence, a cautious monetary policy-maker is well-advised to take monetary policy decisions under the assumption that the economy is characterised by a substantial degree of inflation persistence until strong evidence in favour of a low-inflation regime has emerged. In this context, we also show that using pooled forecasts can serve as a means of insuring the policy-maker against the related risk arising from the use of the wrong forecasting model when there is uncertainty on how to model the inflation process.

Regarding the operating characteristics of simple interest-rate rules that are designed with a view to achieving robustness to largely different degrees of structural inflation persistence, we show that robust rules respond to inflation relatively aggressively and incorporate a substantial degree of inertia. Incidentally, we find that a relatively aggressive first-difference rule which relates changes in the short-term nominal interest rate to the one-year-ahead inflation forecast and the current output gap already goes a long way towards making monetary policy robust to uncertainty regarding the degree of inflation persistence. To the extent that such a rule is found to perform remarkably well under both types of staggered contracts and in the light of the considerable uncertainty about how to model euro area inflation, we tentatively conclude that such a rule may serve as a useful benchmark for model-based evaluations of monetary policy in the euro area.

There are several directions in which the analysis presented in this paper could be extended. First, while this paper has focused on the robustness of optimised simple interest-rate rules, it would be interesting to also investigate the robustness of the fully optimal policies under commitment which were solely used as a benchmark for evaluating the stabilisation performance of optimised interest-rate rules in this paper. A first attempt in this direction has been undertaken in Angeloni, Coenen and Smets (2003), though a more rigorous analysis using techniques developed in Giannoni and Woodford (2002) is left for future research. Second, in the light of the good performance of first-difference rules under both types of staggered contracts, it would be interesting to compare the robustness of rules which target the price level instead of the inflation rate, or a combination of both. Using a simpler theoretical framework, an initial study relevant to this has been undertaken by Batini and Yates (2003). Third, one could approach the robustness analysis using alternative methodologies. For example, one could design interest-rate rules under a minimax criterion aimed at avoiding the worst possible outcome under either of the two staggered contracts specifications. A recent example of robustness analysis using a minimax criterion is the study by Küster and Wieland (2005). Last, but not least, it would be important to check if the central conclusion from the present study is sensitive to alternative models of inflation determination. This could essentially be achieved by extending the analysis to a larger set of empirical models of the inflation process.

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