EUROPEAN CENTRAL BANK
WORKING PAPER SERIES

WORKING PAPER NO. 269

ZERO LOWER BOUND: IS IT A PROBLEM IN THE EURO AREA?

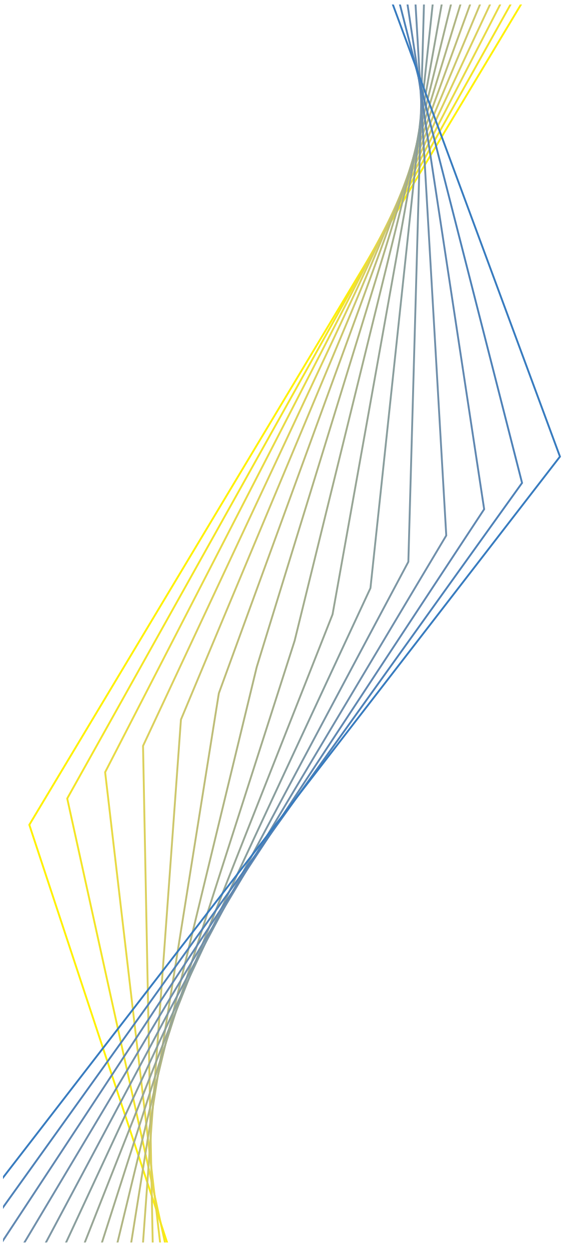
GÜNTER COENEN

September 2003

BACKGROUND STUDY
FOR THE EVALUATION OF
THE ECB'S MONETARY
POLICY STRATEGY

EUROPEAN CENTRAL BANK

WORKING PAPER SERIES



BACKGROUND STUDY
FOR THE EVALUATION OF
THE ECB'S MONETARY
POLICY STRATEGY

WORKING PAPER NO. 269

ZERO LOWER BOUND: IS IT A PROBLEM IN THE EURO AREA?

GÜNTER COENEN[1, 2]

September 2003

---

[1] Correspondence: Günter Coenen, Directorate General Research, European Central Bank, Kaiserstrasse 29, D-60311 Frankfurt am Main, Germany, phone: +49 69 1344-7887, e-mail: gunter.coenen@ecb.int.

[2] The opinions expressed here are those of the author and do not necessarily reflect views of the European Central Bank. Helpful discussions with Ignazio Angeloni, Frank Smets and Volker Wieland are gratefully acknowledged. Any remaining errors are of course the sole responsibility of the author.

This paper can be downloaded without charge from http://www.ecb.int or from the Social Science Research Network electronic library at http://ssrn.com/abstract_id=xxxxxx.

© **European Central Bank, 2003**

Address **Kaiserstrasse 29**
D-60311 Frankfurt am Main
Germany
Postal address **Postfach 16 03 19**
D-60066 Frankfurt am Main
Germany
Telephone **+49 69 1344 0**
Internet **http://www.ecb.int**
Fax **+49 69 1344 6000**
Telex **411 144 ecb d**

All rights reserved.
Reproduction for educational and non-commercial purposes is permitted provided that the source is acknowledged.
The views expressed in this paper do not necessarily reflect those of the European Central Bank.

ISSN 1561-0810 (print)
ISSN 1725-2806 (online)

Table of Contents

Abstract

This paper presents the results of a quantitative study of the implications of the zero lower bound on nominal interest rates which was undertaken in the context of the review of the ECB's monetary policy strategy in Spring 2003. Focusing on the euro area, the paper provides an assessment of the likelihood that the short-term nominal interest rate may be constrained at zero and quantifies how the zero-bound constraint may affect the dynamic behaviour of key macroeconomic variables such as the short-term nominal interest rate, annual inflation and output.

JEL Classification System: E31, E52, E58, E61

Keywords: Zero-interest-rate bound, price stability, nominal rigidities, interest rate rules, euro area

Non-technical summary

This paper presents the results of a quantitative study of the implications of the zero lower bound on nominal interest rates which was undertaken in the context of the review of the ECB’s monetary policy strategy in Spring 2003. Focusing on the euro area, the paper provides an assessment of the likelihood that the short-term nominal interest rate may be constrained at zero and quantifies how the zero-bound constraint may affect the dynamic behaviour of key macroeconomic variables such as the short-term nominal interest rate, annual inflation and output.

The following results have emerged from the evaluation of the consequences of the zero lower bound for monetary policy-making in the euro area:

- Under Taylor’s interest rate rule, the distortions induced by the zero-interest-rate bound are noticeable but economically insignificant once the inflation target is set at 1 percent or higher, if the degree of inflation persistence is low. By contrast, if the degree of inflation persistence is high, the zero lower bound may become a matter of concern for monetary policy-makers who follow Taylor’s rule with inflation targets below 2 percent.

- Additional sensitivity analysis provides some tentative evidence that the adverse consequences of the zero-bound constraint can be alleviated by following an interest rate rule that allows for a substantial degree of inertia – as estimated Taylor-type rules typically do – and responds in a forward-looking manner to one-year ahead forecasts of inflation. The benefits of such a rule appear particularly large if the observed degree of inflation persistence is high.

Overall, these results suggest that the performance of the euro area economy would likely deteriorate somewhat for inflation targets set below 1 percent. The importance of the deterioration is found to depend on the existing degree of inflation persistence, the specification of the interest rate rule and, not least, the level of the equilibrium real interest rate which, as a baseline assumption, has been set equal to 2 percent throughout the study.

1. Introduction and summary

Having achieved consistently low rates of inflation, monetary policy-makers in industrialised countries are confronted with a new challenge, namely how to evade the consequences arising from the zero lower bound on nominal interest rates. In an environment of low inflation the zero lower bound presents a particular challenge for monetary policy-makers because it may limit the usefulness of the principal instrument of monetary policy, that is the short-term nominal interest rate, to lower real interest rates. Even worse, with nominal interest rates constrained at zero, a sequence of deflationary shocks may raise real interest rates and thereby induce or deepen a recession.

This paper revisits the relevance of the zero lower bound for monetary policy-making in the euro area.[1] In consideration of the high degree of uncertainty regarding the determination of euro area-wide inflation, the implications of the zero lower bound are evaluated under different assumptions regarding the characteristics of the euro area inflation process, notably the degree of its persistence. While the degree of inflation persistence is evidently a key determinant of the ability of monetary policy-makers to stabilise inflation relative to output, the importance of the existing degree of inflation persistence seems even heightened when facing the zero lower bound.

For this reason, the evaluation is based on two variants of the estimated small structural model of the euro area developed by Coenen and Wieland (2000) which feature different types of staggered contracts:[2] the nominal wage contracting specification due to Taylor (1980) and the relative real wage contracting specification by Fuhrer and Moore (1995). These two contracting specifications differ with respect to the degree of inflation persistence that they induce, because Fuhrer-Moore-type contracts give more weight to past inflation developments. Both types of contracting specifications were found to describe historical euro area data reasonably well and, thus, neither Taylor nor Fuhrer-Moore-type contracts can be rejected on statistical grounds as an empirical description of inflation dynamics in the euro area.[3]

The following results have emerged from the model-based evaluation of the consequences of the zero lower bound for monetary policy-making in the euro area:

- Under Taylor's interest rate rule, the distortions induced by the zero-interest-rate bound are noticeable but economically insignificant once the inflation target is set at 1 percent or higher, if the

---

[1] Orphanides and Wieland (1998) and Reifschneider and Williams (1999) provided earlier quantitative studies of the relevance of the zero lower bound for monetary policy-making, but these studies were focused on the U.S. economy.

[2] A short exposition of the two alternative contracting specifications is given in the appendix. For more details on the model and the employed estimation methodology see Coenen and Wieland (2000) who refer to the two contracting specifications as the NW and the RWS specification respectively. Within the model, monetary policy-makers are assumed to follow an interest rate rule that relates the short-term nominal interest rate to developments in inflation and deviations of actual output from potential. Changes in the short-term nominal interest rate affect aggregate demand through their impact on the ex-ante long-term real interest rate.

[3] There are other mechanisms which have been proposed in the literature as means to induce lag-dependent inflation dynamics. For example, Galí and Gertler (1999) allow for a fraction of backward-looking firms in the staggered nominal contracts model à la Calvo, which follow a "rule of thumb" when changing contracts, while Christiano, Eichenbaum and Evans (2001) assume that nominal contracts are indexed to past prices. Empirical studies for the euro area by Galí, Gertler and Lopez-Salido (2001) and Smets and Wouters (2002) along these directions also conclude that there is a non-negligible degree of persistence in the euro area inflation process, though it is difficult to quantify this degree precisely.

degree of inflation persistence is low (as represented by Taylor's contracting specification). By contrast, if the degree of inflation persistence is high (as represented by Fuhrer-Moore-type contracts), the zero lower bound may become a matter of concern for monetary policy-makers who follow Taylor's rule with inflation targets below 2 percent.

- Additional sensitivity analysis provides some tentative evidence that the adverse consequences of the zero-bound constraint can be alleviated by following an interest rate rule that allows for a substantial degree of inertia – as estimated Taylor-type rules typically do – and responds in a forward-looking manner to one-year ahead forecasts of inflation. The benefits of such a rule appear particularly large if the observed degree of inflation persistence is high.

Overall, these model-based results suggest that the performance of the euro area economy would likely deteriorate somewhat for inflation targets set below 1 percent. The importance of the deterioration is found to depend on the existing degree of inflation persistence, the specification of the interest rate rule and, not least, the level of the equilibrium real interest rate which, as a baseline assumption, has been set equal to 2 percent throughout the study.

However, while being suggestive, the model-based results call for some further considerations before finally judging the risks and costs arising from the zero-interest-rate bound. First, while clearly pointing to the need of having a "safety margin" to insure the economy against the adverse consequences of the zero bound, the study disregards the costs of tolerating even limited rates of inflation. Apparently, in the absence of distortions like the one due to the zero bound there are good reasons to believe that inflation should be close to zero to reap the full benefits of maintaining price stability. These costs have to be weighed against the costs arising from the zero lower bound.

Second, while Fuhrer-Moore-type wage contracts point to heightened risks and costs, it is not obvious that this type of contracting specification is the most plausible one to describe the determination of euro area-wide inflation in the future. For instance, Coenen and Wieland (2000) show that only Taylor-type contracts fit inflation dynamics for Germany which already enjoyed a credible and predictable monetary policy before joining EMU, while some member countries which experienced a long-lasting disinflation with possibly imperfectly credible monetary policy were better described by Fuhrer-Moore-type contracts. Thus, to the extent that the ECB will likely face a similar environment in the future as did the Bundesbank in Germany, the use of Fuhrer-Moore-type contracts would be considered misleading. In this case, Taylor's contracting specification may be viewed as a more appropriate representation of inflation dynamics in the euro area implying lower risks regarding the zero lower bound.[4]

Third, relevant to both types of staggered contracts specifications, the reported results may possibly underestimate the true risks arising from the zero lower bound, because fiscal policy is assumed to

---

[4] As already indicated in footnote 3, for the time being there is not sufficient information available to reliably discriminate between alternative models of euro area-wide inflation determination and, thus, the need of further empirical work on inflation dynamics in the euro area ranks high.

occasionally boost aggregate demand during sustained periods of deflation to prevent the economy from falling into a deflationary spiral. In the context of this study, such fiscal impetus is necessary because the model economies are not globally stable in the presence of shocks that are large enough to sustain deflationary expectations and to keep the real interest rate above its equilibrium level. However, while resorting to occasional fiscal interventions is analytically convenient to cope with the growing aggregate demand imbalances associated with entrenched deflation, nothing guarantees a priori that such a mechanism would be available in practice.

Fourth, from a conceptual point of view, it may be possible to abate the risks and costs arising from the zero lower bound by further improving the design of monetary policy. For example, monetary policy-makers may lower interest rates pre-emptively when inflation and interest rates have fallen close to zero and the risk of deflation is high. In other words, they may respond more aggressively if they anticipate that the zero-bound constraint will become binding in the near future. Such a non-linear policy response can in principle help offset the distortions arising from the zero lower bound.

Fifth, the variances of the historical shocks used in the model-based evaluation were estimated for the 1980s and 1990s, when the shocks to aggregate demand and aggregate supply were less disruptive than in the 1970s and the zero lower bound never became binding. If the shocks were to be significantly larger, like in a period of substantial economic and/or financial turmoil, the likelihood of hitting the zero lower bound might be far higher and possibly result in substantially larger distortions. By contrast, the baseline assumption of 2 percent for the equilibrium real interest rate is at the lower end of historical estimates. If the assumption for the equilibrium real rate were higher, say, closer to 3 percent, the likelihood that the nominal interest rate is constrained at zero would be correspondingly lower.

Finally, the model that has been used in the analysis is relatively stylised and lacks various mechanisms which may become important to characterise the functioning of the economy in a severe deflationary situation. For example, the model used does not account for the effects operating through the balance sheets of banks, households and non-financial firms which may aggravate the implications of the zero lower bound and re-enforce deflationary trends, as has become most apparent in Japan in the second half of the 1990s. Another limitation to the analysis is that the model relies on the real interest rate as the sole channel to stimulate aggregate demand. In principle, monetary policy-makers can also resort to alternative measures in order to avoid or if necessary to escape deflation. For example, as shown in Coenen and Wieland (2003), they may exploit the exchange rate channel of monetary policy to stimulate aggregate demand and re-inflate the economy via a drastic depreciation of the domestic currency.

The remainder of the paper is organised as follows. Section 2 gives a brief outline of the simulation methodology which is used to investigate the consequences of the zero lower bound for monetary policy-making. Section 3 assesses the frequency of bind of the zero lower bound and investigates the induced effects on the stationary distributions of the short-term nominal interest rate, annual inflation and output. Finally, Section 4 provides some additional sensitivity analysis regarding the robustness of the simulation results to the specification of the monetary policy rule.

2. The methodology

In terms of methodology, the study builds on previous work by Orphanides and Wieland (1998) evaluating the consequences of the zero lower bound using a model of the U.S. economy with a similar, albeit more detailed structure. This methodology employs stochastic dynamic simulations of a particular structural model to assess the frequency with which the nominal interest rate is bounded at zero and to obtain the stationary distributions of key macroeconomic variables under monetary policy rules with alternative inflation targets. To this end, the structural model is subjected repeatedly to a sequence of structural shocks which are drawn from a normal distribution with the covariance matrix of the shocks estimated using historical data.

In preparation for the simulations of the two variants of the small-scale euro area model used in this study the implied sequences of temporary demand and supply shocks have been computed based on euro area data from 1980:Q1 to 1998:Q4. Using the covariance matrix of these historical shocks, 100 sets of artificial normally distributed shocks have been generated with 100 quarters of shocks in each set. For each set, the first 20 quarters of shocks have been discarded in order to guarantee that the effect of the initial values die out. The sets of retained shocks are then used to conduct stochastic simulations under alternative values of the policy-makers inflation target, while imposing the zero-bound constraint on nominal interest rates.[5]

While the non-stochastic version of an estimated interest rate rule has been used for computing the historical demand and supply shocks,[6] it is replaced in the dynamic simulations with the rule proposed by Taylor (1993),[7]

$$i_t = r^* + \pi^* + 1.5 \cdot (\pi_t^{(4)} - \pi^*) + 0.5 \cdot y_t \,,$$

where i is the short-term nominal interest rate, $\pi^{(4)}$ is the annual, year-on-year inflation rate, y is the output gap, π^* denotes the monetary policy-makers' inflation target which determines the steady-state rate of inflation in the model and r^* is the equilibrium real interest rate which is exogenous to the model like the supply side determining potential output. This rule incorporates policy responses to inflation deviations from target and output deviations from its potential. The zero lower bound on the short-term nominal interest rate is then enforced by restricting the interest rate to be equal to zero whenever the Taylor rule prescribes to set it below zero.

---

[5] The simulations have been conducted using an efficient solution algorithm implemented in the PcTroll software package which can cope with the non-linearity arising from the zero-bound constraint on nominal interest rates.

[6] Since weighted averages of European interest rates preceding the formation of European Monetary Union in 1999 seem unlikely to be appropriate as a measure of the euro area-wide historical monetary policy stance, a reaction function for the German short-term nominal interest rate has been estimated. 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. Following work by Clarida, Galí and Gertler (1998), the estimated rule assumes that the short-term nominal interest rate is changed in response to variations of the one-year-ahead forecast of annual average inflation and the current output gap, and also allows for interest-rate smoothing. The estimation period is chosen to start in 1979:Q2, with the formation of the European Monetary System, and ends in 1998:Q4, prior to the launch of the euro in January 1999.

[7] For a critical discussion of the uses of Taylor-style interest rate rules for practical monetary policy-making see ECB (2001).

Of course, the higher the inflation target π^* and/or the equilibrium real interest rate r^*, the higher will be the nominal interest rate in the deterministic steady state and the smaller should be the likelihood that the nominal interest rate is bounded at zero. As a baseline assumption and without loss of generality, the equilibrium interest rate r^* is set equal to 2 percent throughout the study while the consequences of the zero-bound constraint is explored for alternative levels of the inflation target π^*. For a reader who suspects that the level of the equilibrium real interest rate r^* has been higher historically, it should be noted that changes in one parameter can be offset by changes in the other. For example, the results for π^* equal to 1 percent with a baseline assumption of r^* equal to 2 percent also describe the outcome in an economy with r^* equal to 3 percent when π^* is equal to zero.

To ensure the stability of the model with the zero-bound constraint imposed in the presence of large deflationary shocks, a non-linear fiscal expenditure rule is introduced which boosts aggregate demand if the deflationary impetus becomes so severe that the model economy runs the risk of falling into a deflationary spiral.[8] At the same time, if the economy experiences favourable economic conditions over a prolonged period of time, the fiscal rule acts as a drag on aggregate demand in order to support a fiscal position that is close to balance over sufficiently long horizons.[9]

3. The consequences of the zero lower bound on nominal interest rates

This section evaluates the quantitative impact of the zero lower bound on the stationary distributions of key macroeconomic variables such as the short-term nominal interest rate, the annual inflation rate and output by summarising the results of the stochastic dynamic simulations of the two variants of the euro area model for alternative inflation targets that fall in a range between 0 and 4 percent.

a) The frequency of bind of the zero lower bound

To evaluate whether the zero lower bound may limit the effectiveness of monetary policy in a quantitatively significant manner, it is useful to start by assessing the likelihood that nominal rates would be bounded at zero if the economy were subjected to shocks similar in magnitude to those observed historically. Summarising the results of a large number of counterfactual stochastic simulations with alternative inflation targets, **Figure 1** shows the frequency with which the zero lower bound would constrain the monetary policy-makers to set the nominal interest rate below zero if they were to follow

---

[8] See Orphanides and Wieland (1998), pp. 27-28, and Reifschneider and Williams (1999), pp. 21-22, for a more detailed discussion of the need to resort to mechanisms such as occasional fiscal interventions to resolve the global instability problem that arises from shocks that are large enough to sustain deflationary expectations and to keep the real interest rate above its equilibrium level, thereby depressing aggregate demand further and sending the economy in a deflationary spiral.

[9] The extent of the fiscal stimulus is related to the deviation of the actual short-term nominal interest rate i_t (which cannot fall below zero) from the *notional* rate i_t^n that would be prescribed by Taylor's rule in the absence of the zero bound. The fiscal stimulus comes into play with a half-year delay and responds to a moving average of negative deviations of the prescribed interest rate from zero. Government expenditure is restrained in a similar fashion whenever the economy experiences very favourable economic conditions, i.e., in a situation when actual output is so far above potential that the interest rate rule prescribes a rate of more than twice the deterministic steady-state value.

Taylor's rule. The solid line with squares refers to the model with Taylor-type contracts while the solid line with diamonds refers to the model with Fuhrer-Moore-type contracts.

As is evident in the figure, under Taylor-type wage contracts the zero lower bound on nominal interest rates does not represent a quantitatively very important factor for inflation targets set at 1 percent, or higher. For monetary policy-makers following Taylor's rule the zero-bound constraint becomes binding with less than 7 percent frequency with an inflation target of 1 percent. With a target of 2 percent the frequency of bind falls to 2 percent while it is quickly approaching zero for inflation targets exceeding 2 percent. Although the frequency of bind increases considerably as the inflation target approaches zero, the frequency of bind remains well below 20 percent. By contrast, under Fuhrer-Moore-type wage contracts the constraint induced by the zero lower bound is quantitatively much more important. With an inflation target of 1 percent, the constraint becomes binding with about 24 percent frequency, and the frequency approaches 33 percent with an inflation target equal to zero. Even with an inflation target of 2 percent the frequency of bind amounts to 17 percent.

b) The distortion of the stationary distributions of the nominal interest rate, inflation and output

Having provided a quantitative assessment of the likelihood that the nominal interest rate is bounded at zero under Taylor's rule, the following analysis focuses on the extent to which the behaviour of the short-term nominal interest rate, annual inflation and output are distorted with increased frequency of zero interest rates. Quantitative information on the size of the distortion is obtained from the stationary distributions of the variables of interest. These distributions are constructed from the outcomes of the stochastic dynamic simulations with the zero bound being enforced.

Figure 2 first provides summary information regarding the distortion of the means and the variability of the variables of interest under the zero-bound constraint. Specifically, the three panels in the left column of the figure show the induced bias in the means of these variables and the three panels on the right the induced bias in their standard deviations. The benchmarks for comparison are the statistics of the stationary distributions in the absence of the zero-bound constraint, or – equivalently – when the inflation target is sufficiently high such that the frequency of bind is essentially zero.

Starting with the results for the model incorporating Taylor-type wage contracts (solid lines with squares), it can be seen in the upper left panel of **Figure 2** that the zero-bound constraint introduces a small upward bias in the mean of the nominal interest rate for inflation targets near zero. As a consequence, the monetary policy stance is tighter on average than in the absence of the constraint. This, in turn, results in a downward bias in the means of output and inflation, as indicated in the bottom and middle panels on the left, respectively. The quantitative effects, however, are fairly small even with an inflation target equal to zero, with output falling short of potential by 0.10 percentage points on average and with inflation falling below target by 0.05 percentage points on average. The zero-bound constraint also introduces a small upward bias in the standard deviations of inflation and output, because it impairs the policy-makers' ability to stabilise the economy.

$$\Delta i_t = 0.50 \cdot \mathrm{E}_t[\pi^{(4)}_{t+4} - \pi^*] + 0.25 \cdot y_t ,$$

Turning to the results for the model with Fuhrer-Moore-type wage contracts (solid line with diamonds), the upper panel in the left column of **Figure 2** shows that a substantially larger upward bias in the mean of the short-term nominal interest rate emerges if the degree of inflation persistence is high. Similarly, the middle panel in the left reveals that a more sizeable downward bias materialises regarding the mean of inflation. With an inflation target of zero, average inflation falls below target by about 0.23 percentage points; and even with an inflation target of 2 percent the downward bias in the mean of inflation amounts to -0.07 percentage points. Interestingly, the downward bias in the mean of output is only a little larger than under Taylor-type wage contracts. Apparently, this reflects the more recurrent need to resort to fiscal interventions in order to prevent the economy from falling into a deflationary spiral. The more recurrent need to resort to additional fiscal stimulus may also explain the observed downward bias in the standard deviation of inflation.

Finally, the solid and dash-dotted lines in **Figure 3** depict the probability density functions of the inflation gap and the output gap with inflation targets of 0 and 2 percent, respectively. As shown in the upper two panels of the figure, the distortion of the stationary distributions of inflation and output are fairly small under Taylor-type wage contracts even with an inflation target equal to zero, with the left tail of the distributions slightly pronounced. By contrast, as indicated in the lower two panels, the distortions under Fuhrer-Moore-type contracts turn out to be substantially larger, with the probability mass of the output distribution markedly shifted towards the negative region and the probability mass of the inflation distribution somewhat more concentrated near zero.

In summary, the model-based evaluation shows that, under Taylor's rule, the consequences of the zero-bound constraint are noticeable but fairly small once the inflation target is set at 1 percent or higher, if the degree of inflation persistence is low (as represented by Taylor's wage contracting specification). By contrast, if the degree of inflation persistence is high (as represented by Fuhrer-Moore-type wage contracts), the zero lower bound may become a matter of concern for monetary policy-makers who follow Taylor's rule if the inflation target falls below 2 percent.

4. Further sensitivity analysis

So far, the consequences of the zero lower bound have been investigated under the assumption that the monetary policy-makers follow Taylor's rule. To assess the sensitivity of the stochastic simulation results to alternative specifications of the monetary policy rule, this section summarises the results obtained under a forecast-based first-difference rule which relates the change in the interest rate to the one-year ahead forecast of annual inflation and the current output gap,

$$\Delta i_t = 0.50 \cdot \mathrm{E}_t[\pi^{(4)}_{t+4} - \pi^*] + 0.25 \cdot y_t ,$$

with the response to the forecast of the inflation gap calibrated to be somewhat stronger than to the current output gap. Here, Δ denotes the first-difference operator and $\mathrm{E}_t[\cdot]$ indicates the model-consistent forecast, using information available in period t.

The choice of the above forecast-based first-difference rule reflects three considerations. First, the specification in first differences implies a relatively small impact response of the nominal interest rate compared to the impact response under the static Taylor rule. Thus, one may conjecture a priori that the likelihood of hitting the zero lower bound under the first-difference rule is reduced in response to economic shocks.[10] Second, it has been argued that the adverse consequences of the zero-bound constraint can be relieved by a more forward-looking response to anticipated deflation. Finally, it is shown in Coenen (2003) that a calibrated forecast-based first-difference rule similar to that above performs remarkably well across the two alternative models of inflation determination used. Thus, it appears to represent a robust benchmark rule for model-based evaluations of monetary policy in the presence of uncertainty about the prevailing degree of inflation persistence.

Regarding the likelihood that the nominal interest rate is bounded at zero, **Figure 4** reveals that the frequency of bind drops by one fourth to one third under either of the two contracting specifications if monetary policy follows the calibrated forecast-based first-difference rule instead of Taylor's rule. For example, with an inflation target set equal to 1 percent, the frequency of bind under Taylor's wage contracting specification is reduced from 7 to 5 percent, while the frequency of bind under Fuhrer-Moore-type wage contracts falls form 24 to 16 percent.

As to the stationary distributions of the variables of interest, **Figure 5** indicates that the zero-bound constraint under the calibrated forecast-based first-difference rule induces the same kind of distortions as under Taylor's rule. However, while there is little change regarding the bias in the means and standard deviations under Taylor-type contracts, a number of visible changes occur under the contracting specification due to Fuhrer and Moore. For example, when comparing the lower right panels in **Figure 5** and **Figure 2** it can be seen that the upward bias in the standard deviation of output is significantly reduced. At the same time, the bias in the standard deviation of inflation has reversed its sign, while the downward bias in the mean rate of inflation is noticeably raised. Apparently, these changes reflect the less frequent need to resort to fiscal interventions in order to prevent the economy from falling into a deflationary spiral.

Finally, **Figure 6** shows the probability density functions of the inflation gap and the output gap for inflation targets set equal to 0 and 2 percent, respectively. Evidently, the shape of the stationary distributions is distorted less under the forecast-based first-difference rule when compared with the stationary distributions under Taylor's rule in **Figure 3**. This is most obvious for the distribution of the output gap under Fuhrer-Moore-type wage contracts when contrasting the lower right panels of the two figures. While the distribution of the output gap is still skewed towards the left, the probability mass is shifted less markedly to the negative region of the distribution.

---

[10] At the same time, the first-difference rule exhibits a substantial degree of inertia ("smoothing"), as estimated interest rate rules typically do. Because aggregate demand is modelled to depend on the ex-ante long-term real interest rate, interest inertia increases the effectiveness of monetary policy via the private sector's anticipation of future interest rate moves as prescribed by the expectation hypothesis of the term structure.

In summary, the sensitivity analysis provides some tentative evidence that the adverse consequences arising from the zero-bound constraint can be alleviated by following an interest rate rule that allows for a substantial degree of inertia and eventually responds in a forward-looking manner to one-year ahead forecasts of inflation. The benefits appear particularly large if the observed degree of inflation persistence is high.

References

Christiano, L.J., M. Eichenbaum and C. Evans, 2001, "Nominal rigidities and the dynamic effects of a shock to monetary policy", NBER Working Paper No. W8403, July.

Clarida, R., J. Galí and M. Gertler, 1998, "Monetary policy rules in practice: Some international evidence", European Economic Review, 42, 1033-1067.

Coenen, G., 2003, "Inflation persistence and robust monetary policy design", mimeo, European Central Bank, forthcoming in the ECB Working Paper Series.

Coenen, G. and V. Wieland, 2000, "A small estimated euro area model with rational expectations and nominal rigidities", ECB Working Paper No. 30, September, forthcoming in the European Economic Review.

Coenen, G. and V. Wieland, 2003, "The zero-interest-rate bound and the role of the exchange rate for monetary policy in Japan", ECB Working Paper No. 218, March, forthcoming in the Journal of Monetary Economics.

ECB, 2001, "Issues related to monetary policy rules", ECB Monthly Bulletin, October.

Fuhrer, J.C. and G.R. Moore, 1995, "Inflation persistence", Quarterly Journal of Economics, 110, 127-160.

Galí, G. and M. Gertler, 1999, "Inflation dynamics: A structural econometric analysis", Journal of Monetary Economics, 44, 195-222.

Galí, G., M. Gertler and D. Lopez-Salido, 2001, "European inflation dynamics", European Economic Review, 45, 1237-1270.

Orphanides, A. and V. Wieland, 1998, "Price stability and monetary policy effectiveness when nominal interest rates are bounded at zero", Finance and Economics Discussion Series, 98-35, Board of Governors of the Federal Reserve System, June.

Reifschneider, D.L. and J.C. Williams, 1999, "Three lessons for monetary policy in a low inflation era", Finance and Economics Discussion Series, 99-44, Board of Governors of the Federal Reserve System, September.

Smets, F. and R. Wouters, 2002, "An estimated stochastic dynamic general equilibrium model of the euro area", ECB Working Paper No. 171, August.

Taylor, J.B., 1980, "Aggregate dynamics and staggered contracts", Journal of Political Economy, 88, 1-24.

Taylor, J.B., 1993, "Discretion versus policy rules in practice", Carnegie-Rochester Conference Series on Public Policy, 39, 195-214.

Appendix: The staggered wage contracting specifications

The staggered contracts models of Taylor (1980) and Fuhrer and Moore (1995) assume that workers negotiate long-term nominal wage contracts by comparing the current wage contract 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 is adjustable at a 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.

Taylor-type wage contracts:

Under Taylor's specification, 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 deviation of output from its potential over this period, y_{t+i},

$$x_t = \mathrm{E}_t\left[\sum_{i=0}^{3} f_i p_{t+i} + \gamma \sum_{i=0}^{3} f_i y_{t+i}\right] + \varepsilon_t \ ,$$

where the aggregate price level p_t is expressed as the weighted average of current and previously negotiated contract wages, x_{t-i}, which are still in effect,

$$p_t = \sum_{i=0}^{3} f_i x_{t-i}$$

with $f_i > 0$, $f_i > f_{i+1}$ and $\sum_i f_i = 1$.

The expectation operator $\mathrm{E}_t[\cdot]$ indicates the optimal forecast of a particular variable conditional on all information available in period t and the white-noise shock ε_t summarises other short-term influences.

Since the price indices p_{t+i} reflect contemporaneous and preceding contract wages, Taylor's contracting specification 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. If wage setters expect output to exceed potential, $y_{t+i} > 0$, they adjust the current contract wage upwards relative to overlapping contracts. The sensitivity of contract wages to excess demand is measured by γ.

Fuhrer-Moore-type wage contracts:

Under the specification by Fuhrer and Moore, workers negotiating their nominal wage compare the implied real contract wage 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},

$$x_t - p_t = \mathrm{E}_t\left[\sum_{i=0}^{3} f_i v_{t+i} + \gamma \sum_{i=0}^{3} f_i y_{t+i}\right] + \varepsilon_t \ ,$$

where

$$v_t = \sum_{i=0}^{3} f_i (x_{t-i} - p_{t-i}) \ .$$

Figure 1: Frequency of bind of the zero lower bound on nominal interest rates under Taylor's rule

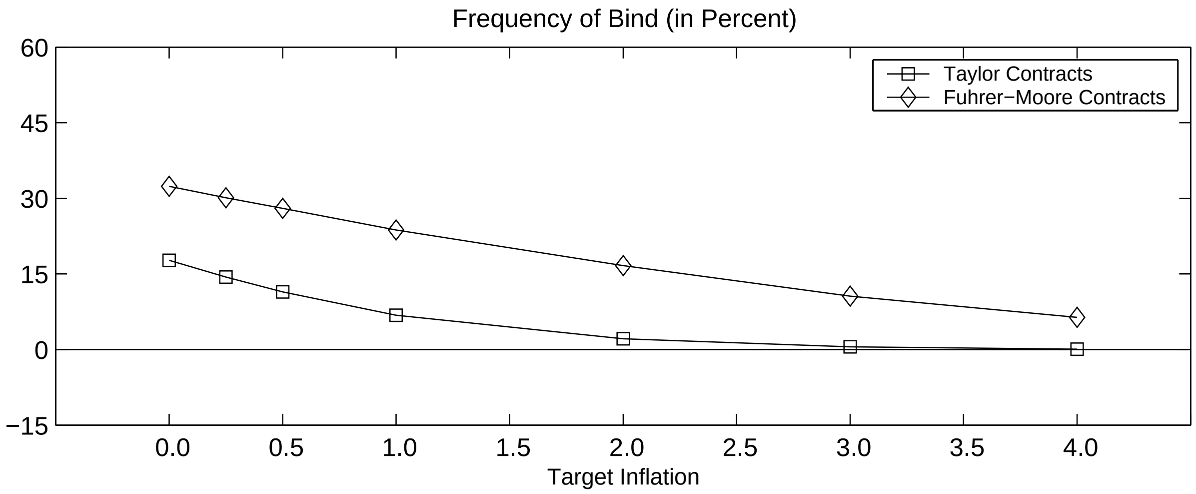
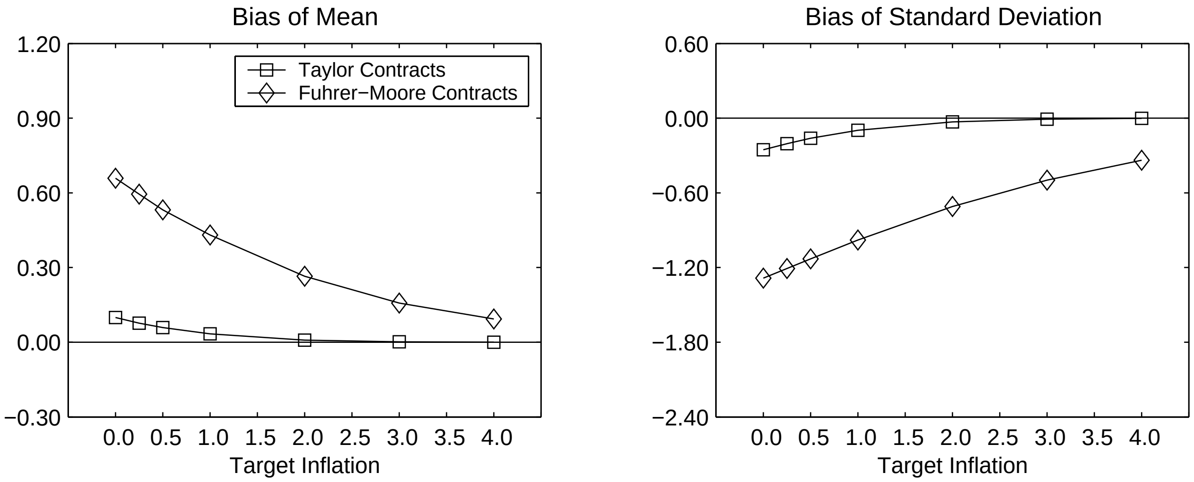
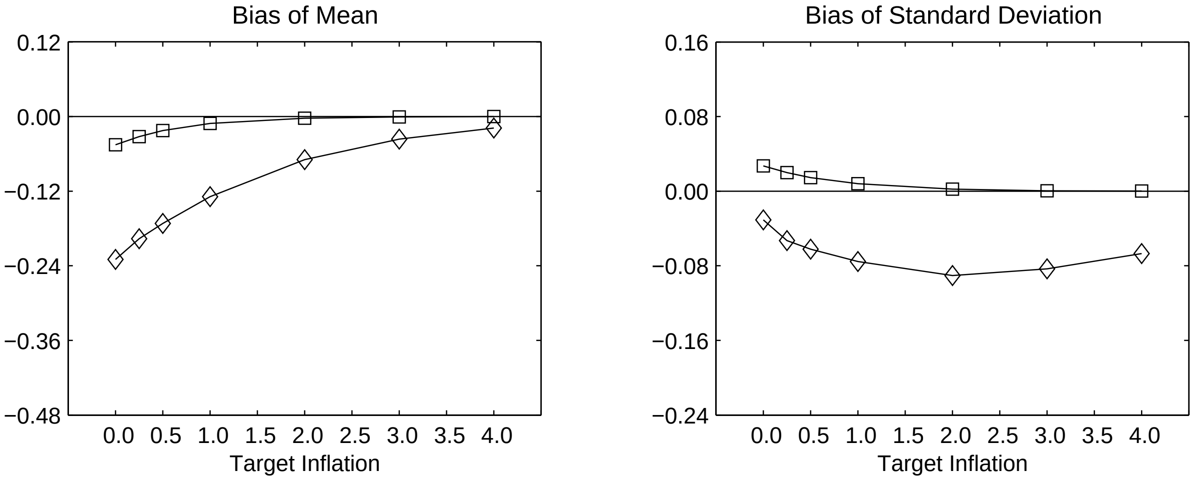


Figure 2: Distortion of the stationary distributions under Taylor's rule

a) Distortion of the stationary distribution of nominal interest rates



b) Distortion of the stationary distribution of inflation



c) Distortion of the stationary distribution of output

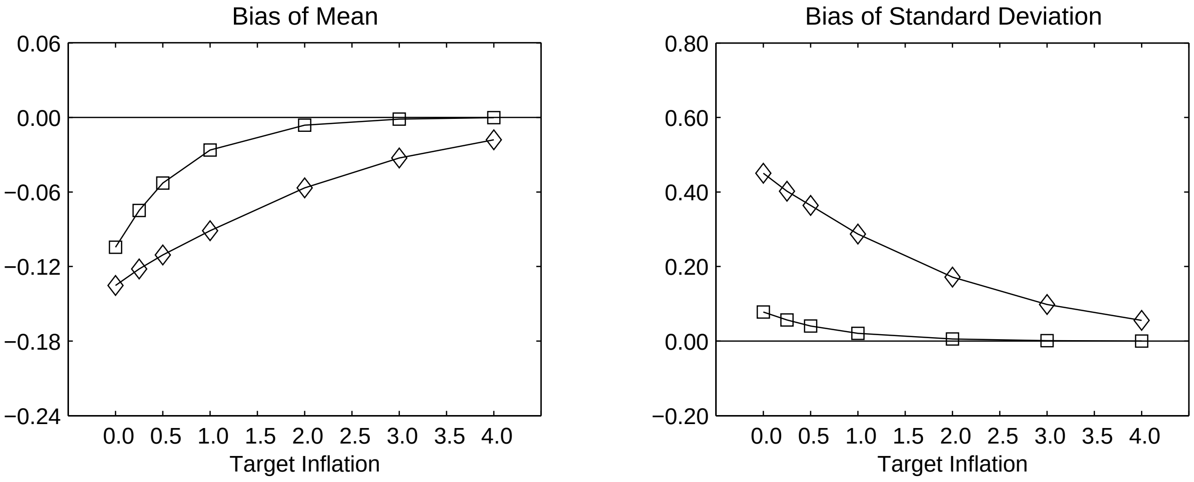
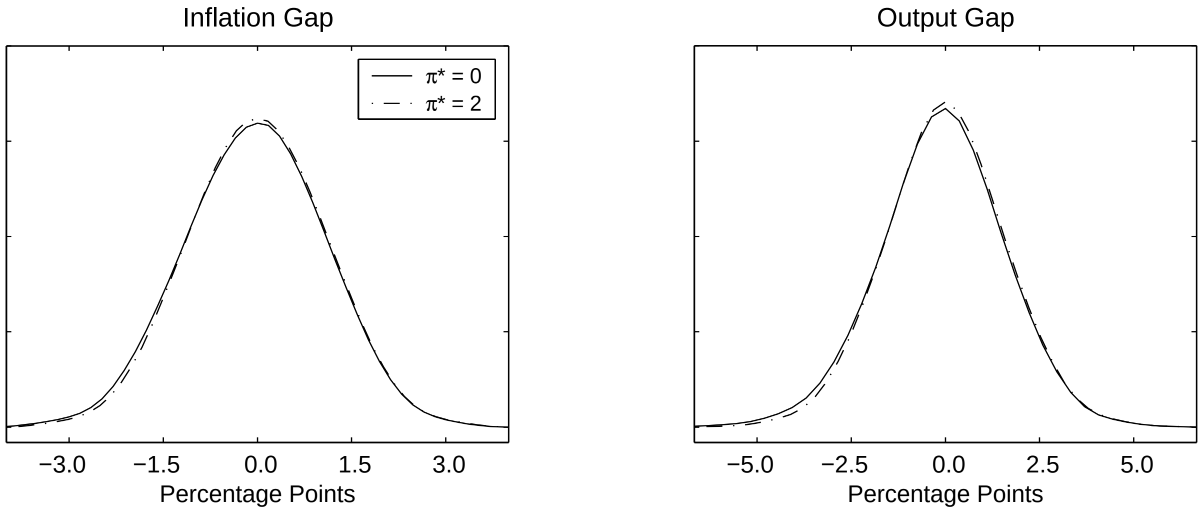


Figure 3: Stationary distributions of the inflation gap and the output gap under Taylor's rule

a) Taylor-type contracts



b) Fuhrer-Moore-type contracts

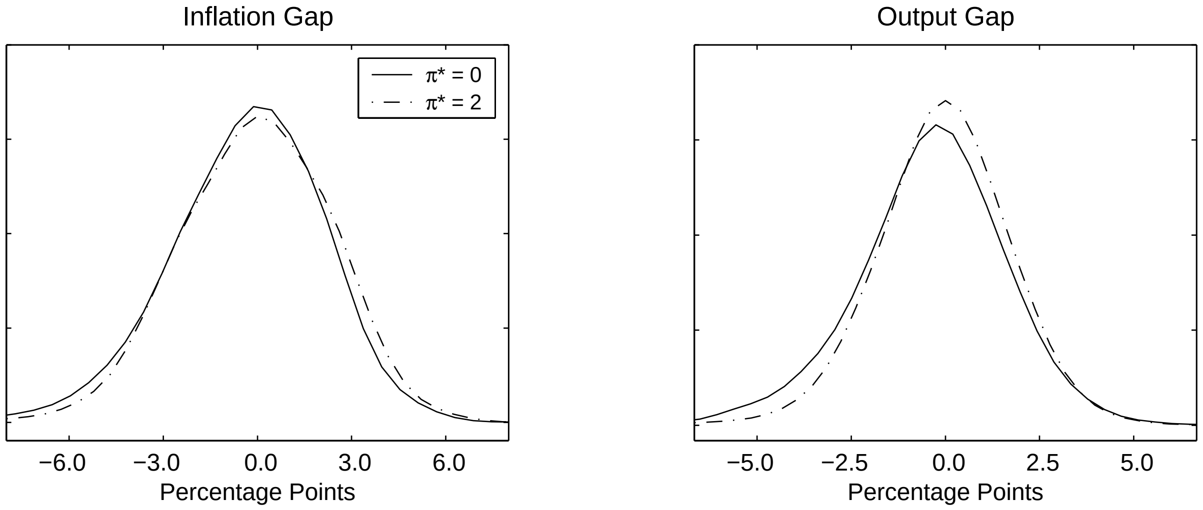


Figure 4: Frequency of bind of the zero lower bound on nominal interest rates under a forecast-based first-difference rule

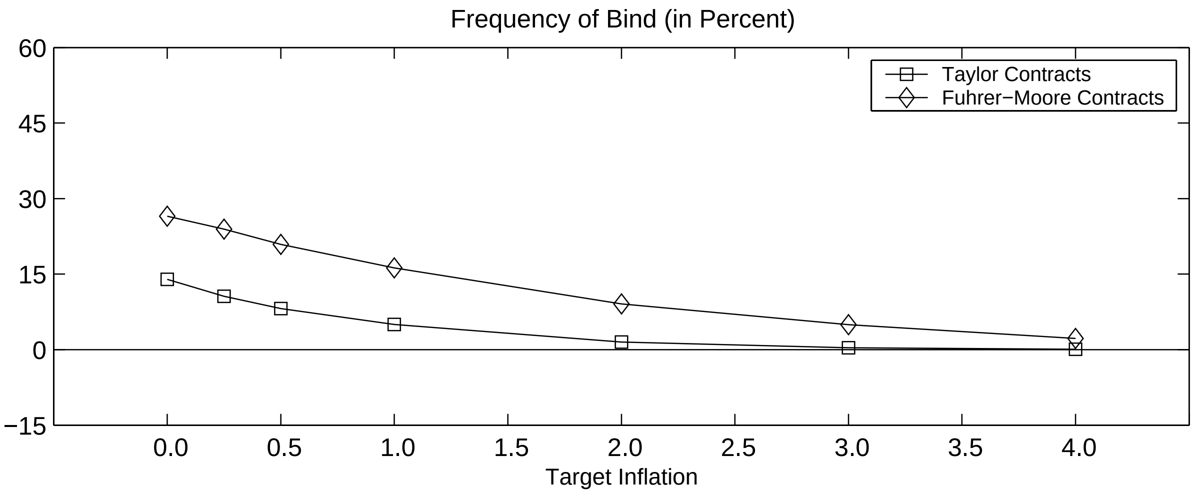
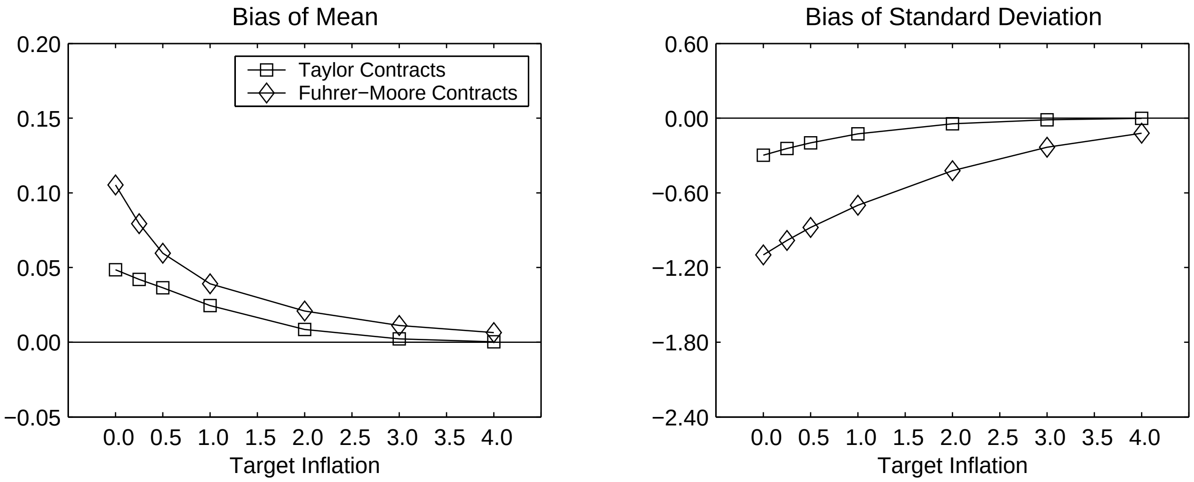
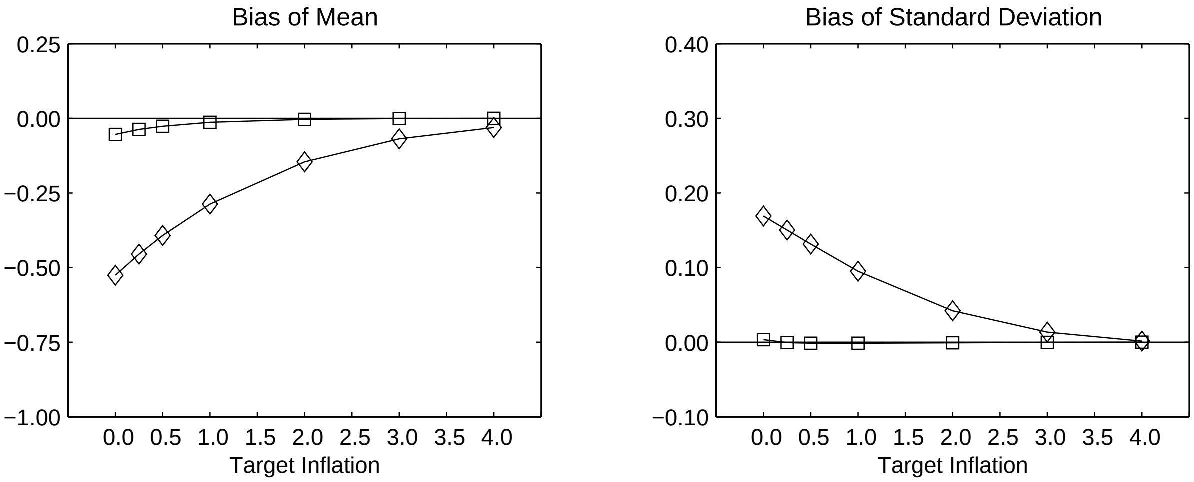


Figure 5: Distortion of the stationary distributions under a forecast-based first-difference rule

a) Distortion of the stationary distribution of nominal interest rates



b) Distortion of the stationary distribution of inflation



c) Distortion of the stationary distribution of output

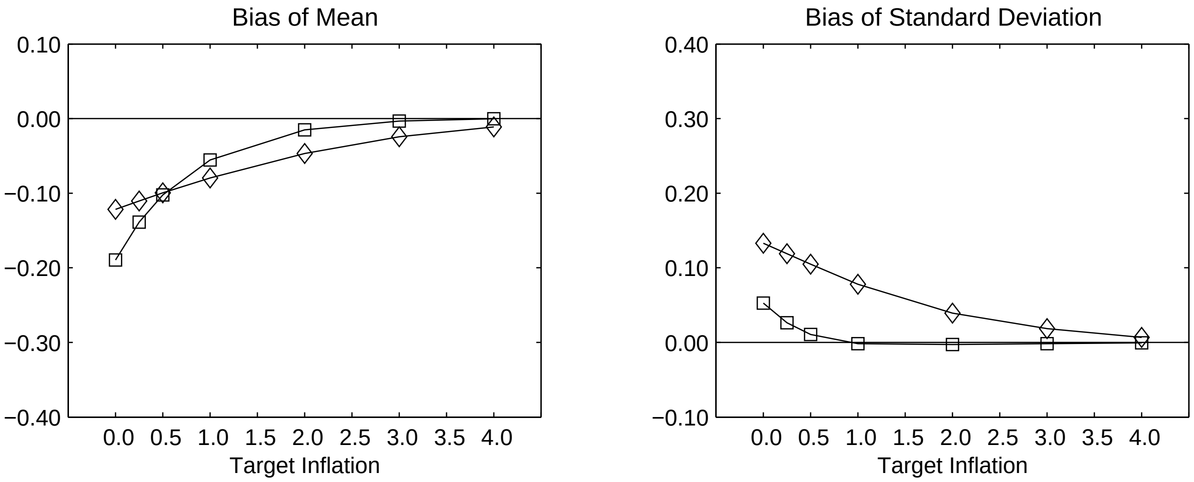
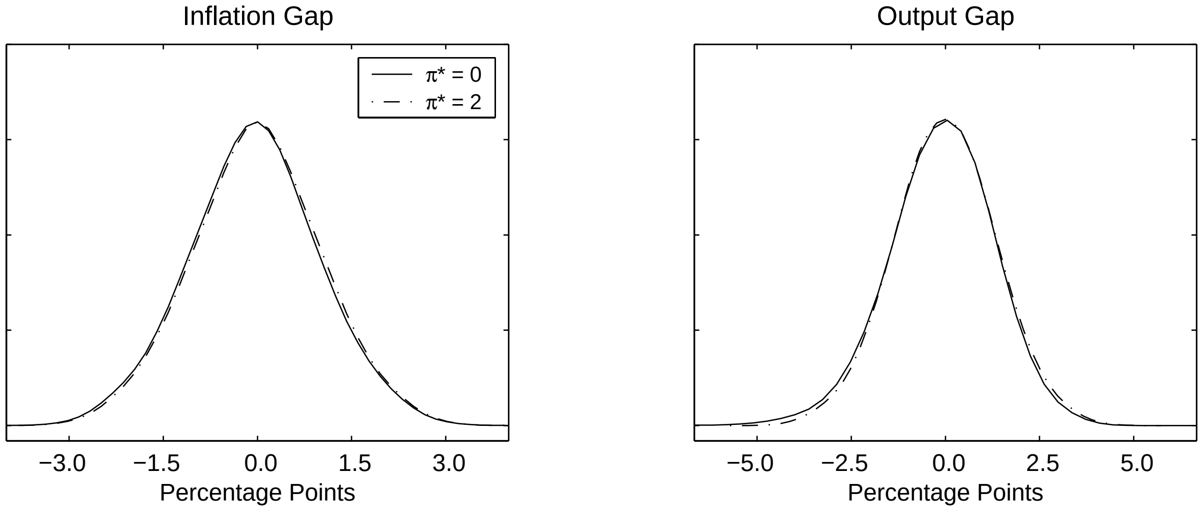
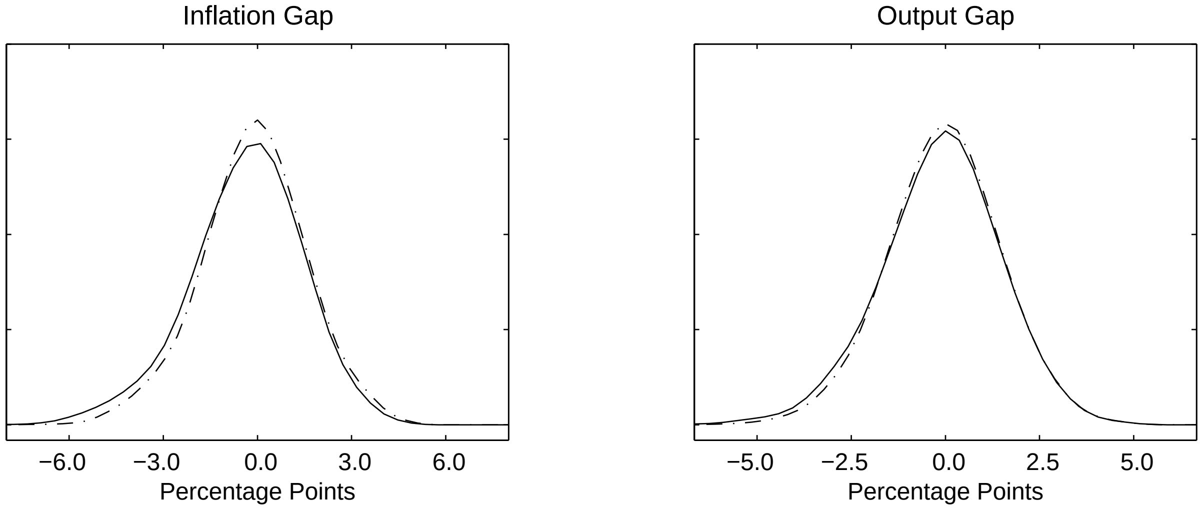


Figure 6: Stationary distributions of the inflation gap and the output gap under a forecast-based first-difference rule

a) Taylor-type contracts



b) Fuhrer-Moore type contracts



European Central Bank working paper series

For a complete list of Working Papers published by the ECB, please visit the ECB's website (http://www.ecb.int).

202 "Aggregate loans to the euro area private sector" by A. Calza, M. Manrique and J. Sousa, January 2003.

203 "Myopic loss aversion, disappointment aversion and the equity premium puzzle" by D. Fielding and L. Stracca, January 2003.

204 "Asymmetric dynamics in the correlations of global equity and bond returns" by L. Cappiello, R.F. Engle and K. Sheppard, January 2003.

205 "Real exchange rate in an inter-temporal n-country-model with incomplete markets" by B. Mercereau, January 2003.

206 "Empirical estimates of reaction functions for the euro area" by D. Gerdesmeier and B. Roffia, January 2003.

207 "A comprehensive model on the euro overnight rate" by F. R. Würtz, January 2003.

208 "Do demographic changes affect risk premiums? Evidence from international data" by A. Ang and A. Maddaloni, January 2003.

209 "A framework for collateral risk control determination" by D. Cossin, Z. Huang, D. Aunon-Nerin and F. González, January 2003.

210 "Anticipated Ramsey reforms and the uniform taxation principle: the role of international financial markets" by S. Schmitt-Grohé and M. Uribe, January 2003.

211 "Self-control and savings" by P. Michel and J.P. Vidal, January 2003.

212 "Modelling the implied probability of stock market movements" by E. Glatzer and M. Scheicher, January 2003.

213 "Aggregation and euro area Phillips curves" by S. Fabiani and J. Morgan, February 2003.

214 "On the selection of forecasting models" by A. Inoue and L. Kilian, February 2003.

215 "Budget institutions and fiscal performance in Central and Eastern European countries" by H. Gleich, February 2003.

216 "The admission of accession countries to an enlarged monetary union: a tentative assessment" by M. Ca'Zorzi and R. A. De Santis, February 2003.

217 "The role of product market regulations in the process of structural change" by J. Messina, March 2003.

218 “The zero-interest-rate bound and the role of the exchange rate for monetary policy in Japan” by G. Coenen and V. Wieland, March 2003.

219 “Extra-euro area manufacturing import prices and exchange rate pass-through” by B. Anderton, March 2003.

220 “The allocation of competencies in an international union: a positive analysis” by M. Ruta, April 2003.

221 “Estimating risk premia in money market rates” by A. Durré, S. Evjen and R. Pilegaard, April 2003.

222 “Inflation dynamics and subjective expectations in the United States” by K. Adam and M. Padula, April 2003.

223 “Optimal monetary policy with imperfect common knowledge” by K. Adam, April 2003.

224 “The rise of the yen vis-à-vis the (“synthetic”) euro: is it supported by economic fundamentals?” by C. Osbat, R. Rüffer and B. Schnatz, April 2003.

225 “Productivity and the (“synthetic”) euro-dollar exchange rate” by C. Osbat, F. Vijselaar and B. Schnatz, April 2003.

226 “The central banker as a risk manager: quantifying and forecasting inflation risks” by L. Kilian and S. Manganelli, April 2003.

227 “Monetary policy in a low pass-through environment” by T. Monacelli, April 2003.

228 “Monetary policy shocks – a nonfundamental look at the data” by M. Klaeffing, May 2003.

229 “How does the ECB target inflation?” by P. Surico, May 2003.

230 “The euro area financial system: structure, integration and policy initiatives” by P. Hartmann, A. Maddaloni and S. Manganelli, May 2003.

231 “Price stability and monetary policy effectiveness when nominal interest rates are bounded at zero” by G. Coenen, A. Orphanides and V. Wieland, May 2003.

232 “Describing the Fed’s conduct with Taylor rules: is interest rate smoothing important?” by E. Castelnuovo, May 2003.

233 “The natural real rate of interest in the euro area” by N. Giammarioli and N. Valla, May 2003.

234 “Unemployment, hysteresis and transition” by M. León-Ledesma and P. McAdam, May 2003.

235 “Volatility of interest rates in the euro area: evidence from high frequency data” by N. Cassola and C. Morana, June 2003.

236 “Swiss monetary targeting 1974-1996: the role of internal policy analysis” by G. Rich, June 2003.

237 “Growth expectations, capital flows and international risk sharing” by O. Castrén, M. Miller and R. Stiegert, June 2003.

238 “The impact of monetary union on trade prices” by R. Anderton, R. E. Baldwin and D. Taglioni, June 2003.

239 “Temporary shocks and unavoidable transitions to a high-unemployment regime” by W. J. Denhaan, June 2003.

240 “Monetary policy transmission in the euro area: any changes after EMU?” by I. Angeloni and M. Ehrmann, July 2003.

241 Maintaining price stability under free-floating: a fearless way out of the corner?” by C. Detken and V. Gaspar, July 2003.

242 “Public sector efficiency: an international comparison” by A. Afonso, L. Schuknecht and V. Tanzi, July 2003.

243 “Pass-through of external shocks to euro area inflation” by E. Hahn, July 2003.

244 “How does the ECB allot liquidity in its weekly main refinancing operations? A look at the empirical evidence” by S. Ejerskov, C. Martin Moss and L. Stracca, July 2003.

245 “Money and payments: a modern perspective” by C. Holthausen and C. Monnet, July 2003.

246 “Public finances and long-term growth in Europe – evidence from a panel data analysis” by D. R. de Ávila Torrijos and R. Strauch, July 2003.

247 “Forecasting euro area inflation: does aggregating forecasts by HICP component improve forecast accuracy?” by K. Hubrich, August 2003.

248 “Exchange rates and fundamentals” by C. Engel and K. D. West, August 2003.

249 “Trade advantages and specialisation dynamics in acceding countries” by A. Zaghini, August 2003.

250 “Persistence, the transmission mechanism and robust monetary policy” by I. Angeloni, G. Coenen and F. Smets, August 2003.

251 “Consumption, habit persistence, imperfect information and the lifetime budget constraint” by A. Willman, August 2003.

252 “”Interpolation and backdating with a large information set” by E. Angelini, J. Henry and M. Marcellino, August 2003.

253 “Bond market inflation expectations and longer-term trends in broad monetary growth and inflation in industrial countries, 1880-2001” by W. G. Dewald, September 2003.

254 "Forecasting real GDP: what role for narrow money?" by C. Brand, H.-E. Reimers and F. Seitz, September 2003.

255 "Is the demand for euro area M3 stable?" by A. Bruggeman, P. Donati and A. Warne, September 2003.

256 "Information acquisition and decision making in committees: a survey" by K. Gerling, H. P. Grüner, A. Kiel and E. Schulte, September 2003.

257 "Macroeconomic modelling of monetary policy" by M. Klaeffling, September 2003.

258 "Interest rate reaction functions and the Taylor rule in the euro area" by P. Gerlach-Kristen, September 2003.

259 "Implicit tax co-ordination under repeated policy interactions" by M. Catenaro and J.-P. Vidal, September 2003.

260 "Aggregation-theoretic monetary aggregation over the euro area, when countries are heterogeneous" by W. A. Barnett, September 2003.

261 "Why has broad money demand been more stable in the euro area than in other economies? A literature review" by A. Calza and J. Sousa, September 2003.

262 "Indeterminacy of rational expectations equilibria in sequential financial markets" by P. Donati, September 2003.

263 "Measuring contagion with a Bayesian, time-varying coefficient model" by M. Ciccarelli and A. Rebucci, September 2003.

264 "A monthly monetary model with banking intermediation for the euro area" by A. Bruggeman and M. Donnay, September 2003.

265 "New Keynesian Phillips Curves: a reassessment using euro-area data" by P. McAdam and A. Willman, September 2003.

266 "Finance and growth in the EU: new evidence from the liberalisation and harmonisation of the banking industry" by D. Romero de Ávila, September 2003.

267 "Comparing economic dynamics in the EU and CEE accession countries" by R. Süppel, September 2003.

268 "The output composition puzzle: a difference in the monetary transmission mechanism in the euro area and the US" by I. Angeloni, A. K. Kashyap, B. Mojon and D. Terlizzese, September 2003.

269 "Zero lower bound: is it a problem with the euro area?" by G. Coenen, September 2003.