Risks to Price Stability and the Zero Lower Bound: A Real-Time Assessment for the Euro Area

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Abstract

This paper employs stochastic simulations of the New Area-Wide Model—a micro-founded open-economy model developed at the ECB—to investigate the consequences of the zero lower bound on nominal interest rates for the evolution of risks to price stability in the euro area in the wake of the financial crisis of 2008-09. Using a formal measure of the *balance of risks*, which is derived from policy-makers' preferences about inflation outcomes, we show that downside risks to price stability were considerably greater than upside risks during the first half of 2009, followed by a gradual re-balancing of these risks until mid-2011. The risk balance turned negative again thereafter, triggered by the re-intensification of the crisis due to elevated tensions in euro area sovereign debt markets. We find that the lower bound has induced a noticeable downward bias to the risk balance throughout the crisis period because of the implied amplification of deflation risks. We also find that, with nominal interest rates close to zero, forward guidance can be successful in mitigating downward risks to price stability, but it may also create upside risks over the medium term if not calibrated carefully.

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1 Introduction

The financial crisis of 2008-09 has posed fundamental challenges for the assessment of risks to price stability in the euro area. The sharp contraction in economic activity at the onset of the crisis put downward pressure on prices beyond the short-run impact of the drop in commodity prices observed at that time. This gave rise to concerns that the euro area may eventually enter a situation leading to a sustained and broad-based fall in the aggregate price level, i.e. deflation.[1] The European Central Bank (ECB), like other major central banks around the world, responded to the unfolding events by rapidly reducing its key interest rates to historically low levels in order to support aggregate demand and to forestall a further loss of confidence. While the downward pressure on prices eventually receded with the start of a muted, albeit vulnerable recovery in late 2009, the outlook for the economy has remained subject to a heightened degree of uncertainty.[2]

Against this background, we aim to provide a model-based narrative of the evolution of the risks to price stability in the euro area in the wake of the financial crisis. We do so by employing stochastic simulations of the ECB's New Area-Wide Model (NAWM), a micro-founded open-economy model of the euro area designed for forecasting and policy analysis (see Coenen, Christoffel and Warne, 2008). Importantly, with short-term nominal interest rates at historically low levels, the simulations recognise the existence of the zero lower bound on nominal interest rates which limits the scope for monetary policy to provide additional stimulus using its standard instrument.[3] Moreover, the simulations are conducted in a real-time setting, covering the period from late 2008 to the end of 2011. Thus they enable us to construct predictive distributions for the inflation outlook which capture the uncertainty pertaining to unforeseen future events at different points in time. To enhance the realism of our risk assessment, we construct the model-based predictive distributions using Consensus Economics forecast vintages as a reference point. In so doing, we account for the sequence of revisions that were made to inflation forecasts over time on the basis of a broader information set as well as different models and analytical perspectives. These revisions have often been substantial, with notable consequences for the assessment of the risks to price stability in the euro area.

[1] See, e.g., IMF (2009).

[2] In fact, severe setbacks in the recovery were due to the re-intensification of the crisis on account of elevated tensions in euro area sovereign debt markets in the course of 2010 and 2011.

[3] The ECB also implemented a number of non-standard monetary policy measures, including the provision of unlimited liquidity to the banking system, to sustain financial intermediation and to maintain the availability of credit to the private sector; see ECB (2010a). For an analysis of the fiscal response to the crisis in the euro area, see European Commission (2009), ECB (2010b) and Coenen, Straub and Trabandt (2012, 2013).

Our analysis of risks to price stability builds on a literature that has used structural macroeconomic models to study the consequences of the zero lower bound on nominal interest rates for the efficacy of monetary policy, including studies by Reifschneider and Williams (2000), Coenen, Orphanides and Wieland (2004) and Williams (2009). While these studies have focused on how the zero lower bound affects the properties of the models' steady-state distributions with a view to designing monetary policy strategies that help to mitigate the zero lower bound impact, we study the evolution of risks to price stability during the crisis on the basis of model-based predictive distributions. A similar approach has been taken by Chung, Laforte, Reifschneider and Williams (2011), yet with a focus on assessing the likelihood that a range of different models would have predicted the actual macroeconomic outcomes prior to the onset of the crisis.

Our model-based assessment of risks to price stability shows that *deflation risks* (defined as the probability of observing at least four consecutive quarters of negative annual inflation rates over the respective forecast horizon) were highest for the March and June 2009 Consensus Economics forecast vintages. They diminished subsequently, but edged up again in the second half of 2011 following the re-intensification of the crisis due to elevated tensions in euro area sovereign debt markets. By contrast, *excess inflation risks* (defined as the probability of observing at least four consecutive quarters of annual inflation above 2%) were lowest for the early 2009 forecast vintages and increased thereafter. A formal measure of the *balance of risks* advocated by Kilian and Manganelli (2007), which is based on policy-makers' preferences about inflation outcomes and takes the severity of deflation and excess inflation risks into account, suggests that downside risks were considerably greater than upside risks during the first half of 2009, followed by a gradual re-balancing of these risks until mid-2011. Thereafter the risk balance started to turn negative again. The model-based analysis demonstrates that the lower bound on nominal interest rates has induced a noticeable downward bias to the risk balance throughout the crisis period because of the implied amplification of deflation risks.

Whereas our analysis offers first and foremost a real-time narrative of the consequences of the financial crisis for the evolution of risks to price stability through the lens of the NAWM, the employed methodology of stochastic simulations can also be used to examine the effects of counterfactual policy measures. As an illustration, we examine the effectiveness of providing *forward guidance* concerning the future path of the short-term nominal interest rate as a means to delivering additional stimulus in a situation where nominal interest rates are close to zero and where downside risks to price stability prevail.[4] Within

[4] For an exposition of the theoretical underpinnings of forward guidance at the zero lower bound, see, e.g.,

the NAWM, forward guidance is implemented as the *conditional commitment* to keep the nominal interest rate at the zero lower bound for a certain number of additional quarters, over and above the number of quarters for which the interest rate would be constrained by the zero lower bound in the absence of the conditional commitment. Focusing on the December 2011 forecast vintage as a reference point, the model-based simulations suggest that forward guidance imparts the intended stimulus and can be successful in reducing the prevailing downside risks to price stability. Yet if not carefully calibrated, it may, through its impact on inflation expectations, create higher inflationary momentum than desired, leading to upside risks to price stability over the medium term.

It is important to note that the sizeable effects which we obtain on the basis of simulations with the NAWM are likely to provide an upper bound for the potency of forward guidance to the extent that the commitment in the model-based analysis is perfectly credible. Throughout our analysis we abstract from issues that could arise under imperfect credibility, and focus on the case—as in nearly all of the existing zero lower bound literature—where the policy-maker has a perfect commitment technology. A notable exception is the recent study by Bodenstein, Hebden and Nunes (2012), which considers the case of imperfect credibility and addresses the inherent time inconsistency problem of forward guidance because of the temptation to tighten policy once inflation resurfaces.

The remainder of the paper is organised as follows. Section 2 examines the evolution of deflation and excess inflation risks over the crisis period, focusing on the probabilities of certain deflation and excess inflation events. Section 3 proceeds by introducing and evaluating a formal measure of the balance of risks to price stability and ascertains its sensitivity to alternative assumptions. Section 4 studies the effects of forward guidance; and Section 5 concludes. A brief overview of the NAWM and technical details of the analysis are deferred to appendices.

2 Risks to price stability and the lower bound

Forecasts are a central element in the deliberations of monetary policy-makers regarding the outlook for the economy and the calibration of the stance of monetary policy. Yet point forecasts fail to convey the large uncertainty which pertains to unforeseen events and developments over the forecast horizon. That uncertainty can be captured by density forecasts, or predictive distributions.

Eggertsson and Woodford (2003), Adam and Billi (2006), Nakov (2008), Walsh (2009) and Levin, López-Salido, Nelson and Yun (2010). Woodford (2012) offers a broader perspective on forward guidance, including on the practical experience of the Federal Reserve with the introduction of forward guidance.

In an attempt to characterise the forecast uncertainty prevailing at different points in time over the crisis period and to gauge the evolution of the associated risks to price stability, we will utilise predictive distributions based on the ECB's New Area-Wide Model (NAWM), which is a micro-founded open-economy model of the euro area designed for use in the ECB/Eurosystem staff projections and for policy analysis.[5] In deriving the predictive distributions, we shall allow the short-term nominal interest rate to react to new shocks that may occur over the forecast horizon according to the NAWM's estimated monetary policy rule, while recognising the zero lower bound for nominal interest rates.[6] As we shall demonstrate below, the existence of the zero lower bound has important consequences for the evolution of the risks to price stability over the crisis period.

To the extent that policy-makers do not base their deliberations on any mechanical model-based forecast, however, we start from baseline forecasts that incorporate a wider range of data and account for different models and perspectives, namely the forecast vintages provided by Consensus Economics. These vintages are released at a quarterly frequency in early March, June, September and December of each calendar year. We then employ stochastic simulations of the NAWM to obtain predictive distributions around these baseline forecasts.[7] That is, we rely on a model-based characterisation of uncertainty, including the effects that arise from the zero lower bound on nominal interest rates, but account for the sequence of revisions that were made to the baseline forecasts over time on the basis of a broader information set.[8]

Risks to price stability: March 2009

By means of example, Figure 1 displays the March 2009 Consensus forecast vintage as well as the mean and the 70% and 90% confidence bands of the associated NAWM-based predictive distributions for annual consumer price inflation (measured in terms of the private

[5] For a detailed description of the NAWM, see Christoffel, Coenen and Warne (2008). A sketch of its basic structure is provided in Appendix A.

[6] That is, we do not allow for a feedback from the quantified risks to price stability to the interest-rate prescriptions of the estimated policy rule. Rather, the risk assessment is conducted ex-post on the basis of the model's predictive distributions which depend, inter alia, on the characteristics of the policy rule.

[7] For details on the compilation of the Consensus Economics forecast vintages that we use in the analysis and the construction of our real-time data set, see Appendix B. Technical details on the stochastic simulations that we conduct around the baseline forecasts and on the solution method that we use to solve the NAWM subject to the zero lower bound constraint are provided in Appendix C.

[8] Throughout our paper, we maintain the assumption that the forecasters surveyed by Consensus Economics have not taken into account the consequences of the zero lower bound themselves. This assumption will be correct if the forecasters are agnostic about the lower bound, or if they rely on linear models and tools in producing their forecasts which do not account for the non-linearity induced by the lower bound. Otherwise our analysis may overestimate the importance of the zero lower bound as a factor determining downside risks to price stability. Accordingly, our assessment ought to be seen as providing an upper bound for the importance of downside risks.

consumption deflator), annual real GDP growth and the short-term nominal interest rate (corresponding to the annualised 3-month EURIBOR).

With regard to consumer price inflation (see the upper left panel in Figure 1), an increasing part of the predictive distribution lies below zero, while a substantial part continues to lie above inflation rates consistent with the ECB's quantitative definition of price stability with inflation below, but close to 2%. Accordingly, the distribution is markedly skewed to the downside, and its mean falls increasingly below the Consensus baseline path over the outer years of the forecast horizon. Similar properties are found for the predictive distribution of real GDP growth (see the upper right panel in the figure).

The reason for the asymmetry of the predictive distributions is the fact that, with short-term nominal interest rates having been lowered to unprecedented levels to support the economy in the face of large negative demand shocks, the reaction of monetary policy to new recessionary and deflationary shocks over the forecast horizon is eventually constrained by the zero lower bound on nominal interest rates. In the simulations, this happens with an average incidence of 15.9% across all quarters of the forecast horizon. Correspondingly, the lower bound constraint implies a piling-up and a skew to the upside of the predictive distribution for the short-term nominal interest rate, with the interest rate being somewhat higher on average than in the baseline path (see the lower left panel in Figure 1).[9] If the zero lower bound were not to be taken into account, the predictive distributions for consumer price inflation, real GDP growth and the short-term nominal interest rate would all be symmetric, and their means would be equal to the values in the baseline paths.

In assessing risks to price stability on the basis of the predictive distribution for consumer price inflation, we distinguish downside and upside risks. We associate downside risks with the emergence of *deflation*, which can be defined as the event that annual inflation falls below zero for at least 4 consecutive quarters. This definition is motivated by the widely held belief that negative inflation rates ought to become a concern for policy-makers only in cases where they are persistent and translate into a sustained fall in the aggregate price level.[10] Similarly, we consider upside risks, with the notion of *excess inflation* being defined

[9]In the NAWM, the lower bound is actually imposed at an interest rate level of 65 basis points, reflecting the fact that the interest rate path for the March 2009 forecast vintage is derived from 3-month EURIBOR futures, which differ from market expectations of the EONIA by a spread reflecting counter-party and liquidity risk of about 65 basis points on average over the forecast horizon. In other words, the lower bound considered in the model-based simulations derives from a zero bound on the EONIA, which then translates into a lower bound for the EURIBOR given by the average spread.

[10]The same definition has been used by, e.g., IMF staff when assessing deflation risks in Japan, the United States and the euro area with the Global Projection Model (GPM); see Clinton, Garcia-Saltos, Johnson, Kamenik and Laxton (2010).

as an event that annual inflation is above 2% for at least 4 consecutive quarters.[11] Based on these definitions, the deflation risk, i.e. the probability that the deflation event occurs, is found to equal 13.9% on average across all quarters of the forecast horizon, whereas the excess inflation risk is 11.6%.

Does the March 2009 forecast vintage, and the associated predictive distribution for inflation, signify a period with exceptionally high deflation risks? To address this question we examine next the evolution of the downside and upside risks to price stability over time, from the onset of the crisis in late 2008 onwards.

Risks to price stability: December 2008 to December 2011

Our findings regarding the evolution of the deflation and excess inflation risks from the December 2008 to the December 2011 forecast vintage are summarised in Table 1, while the underlying predictive distributions are shown in Appendix Figure A. As a benchmark for assessing the importance of deflation and excess inflation risks related to individual forecast vintages, we consider the values of the respective risks implied by the predictive distribution for inflation that has been initialised in the NAWM's steady state; see the values in the bottom line of the table.[12] Compared with—in slight abuse of terminology—a *steady-state* deflation risk of 1.5%, our findings indeed suggest that deflation risks in March 2009 were significantly elevated, yet with deflation risks in June 2009 being even somewhat higher, at 14.8% on average. From September 2009 onwards, the deflation risks have gradually diminished, but they edged up again in the second half of 2011 following the re-intensification of the crisis due to the build-up of tensions in some euro area sovereign debt markets.[13] By contrast, excess inflation risks were exceptionally low throughout 2009 and have increased thereafter, reaching a peak in the first half of 2011.

One important factor explaining the heightened deflation risks in the first half of 2009 is the profile of the baseline forecasts for annual inflation; see Appendix Figure A. Following

[11]The confidence bands for consumer price inflation in Figure 1 allow for spells of inflation above 2% and inflation spells below zero that are shorter than 4 consecutive quarters. Since the shortest spell can be only one quarter, the confidence bands represent medium-term as well as short-term risks. The focus of the analysis in this paper is on the former. Probabilities for differing definitions of excess inflation or deflation events can be easily obtained from the predictive distribution.

[12]The NAWM features a steady-state nominal interest rate of 4.4% per annum, which is composed of a steady-state inflation rate of 1.9% per annum, consistent with the ECB's quantitative definition of price stability, and an equilibrium real interest rate of 2.5% per annum.

[13]The estimated probabilities are based on the full length of the respective forecast sample. This means that 9 quarters are included in the sample for the December forecast vintages, 10 for the September, 11 for the June, and 12 for the March vintages; see Appendix B for details. Since the width of the predictive distributions increases with the sample length, there is a small bias in the estimated probabilities in comparison to those obtained when only the first 9 quarters are counted; see Appendix Table A for the corresponding probabilities estimated for a uniform sample length of 9 quarters.

the sharp fall in commodity prices in the second half of 2008, inflation rates decelerated markedly, with a trough below, albeit near zero reached in summer 2009. Owing to base effects and a partial reversal of the previous drop in commodity prices, inflation rates picked up in autumn 2009, even though underlying inflationary pressures remained contained on account of the slack in the economy and on the back of a muted recovery.

A second important factor, which we emphasise in our paper, concerns the role of the zero lower bound on nominal interest rates. The short-term nominal interest rate had been sharply reduced by early 2009 in swift response to the crisis, and the incidence of hitting the lower bound has consequently shifted upward to on average 15.9% in March 2009, compared to a steady-state incidence of 0.3%; see the far right column in Table 1. The even higher lower bound incidence recorded for the June and September 2010 forecast vintages is due to a downward shift in the associated paths of the short-term nominal interest rate; see Appendix Figure A. This downward shift was triggered by the intensification of the crisis during the first half of 2010 as a result of the deteriorating fiscal situation in a number of euro area countries. The heightened lower bound incidence gave rise to an increased skew to the downside of the predictive distributions for both real GDP growth and consumer price inflation, thereby amplifying the prevailing deflation risks. This increased downside skew in turn interacted with the lower bound via a negative feedback-loop, as nominal interest rates could not be lowered to offset such skew, and further elevated the lower bound incidence. Similar developments occurred in the second half of 2011, when the tensions in sovereign debt markets re-intensified.

Nevertheless, the growing impact of the lower bound incidence on deflation risks in 2010 was eventually offset by upward revisions to the baseline forecast for inflation in 2010 and in early 2011 (see Appendix Figure A), with the net effect that deflation risks decreased. Yet with the worsening of sovereign debt market tensions in the second half of 2011, when short-term interest rates were lowered further and market expectations of future interest rates fell to unprecedented levels, the lower bound incidence reached historical heights and deflation risks started to rise again.

Risks to price stability: The calendar year 2011

Whereas Table 1 provides an assessment of the evolution of deflation and excess inflation risks for the forecast vintages from December 2008 to December 2011 and for the full length of the respective forecast horizons, Table 2 zooms in on the risks pertaining to a particular calendar year, namely 2011. This year is covered in full by all our forecast vintages up to March 2011, except for the December 2008 vintage. Deflation risks for 2011 are found to diminish from one forecast vintage to the next, the underlying factors being twofold. First, the forecast horizon is moving forward by one quarter for each consecutive forecast vintage. Therefore, with the predictive distributions gradually fanning out over the forecast horizon, an increasingly smaller part of the predictive distribution for inflation tends to lie below zero in the calendar year 2011. And second, the diminishing deflation risk reflects the successive upward revisions of the baseline forecasts for inflation in 2011; see Appendix Figure A. These two factors are partly off-set by the increased downward bias in the predictive distributions for inflation on account of the heightened zero lower bound incidence in 2011. Similarly, excess inflation risks for 2011 are re-assessed over time to be increasing, following a sequence of downward revisions in 2009 and early 2010.

3 Assessing the balance of risks to price stability

The risk measures in Tables 1 and 2 are given by the probabilities that certain deflation and excess inflation events will occur based on the predictive distributions of the NAWM. Measures of risk, however, may also take the *severity* of the events of concern into account (see, e.g., Machina and Rothschild, 1987). For example, an average excess inflation rate of 2.5% with an excess inflation probability of 20% may be regarded as less risky than an average excess inflation rate of 4% with a probability of 5%. Risk measures that take the severity of events into account were initially considered in the context of portfolio allocation decisions (see Fishburn, 1977, and Holthausen, 1981) but have more recently been adapted to macroeconomic forecasting (see Kilian and Manganelli, 2007).

Loss function-based risk measures
Following Kilian and Manganelli (2007), Figure 2 displays a parametric family of loss functions for the preferences of a policy-maker with respect to alternative inflation outcomes.[14] In line with the exposition in the previous section, it is assumed that the lower bound defining deflation is equal to zero, while excess inflation is determined by the upper bound of 2%. Within these bounds the loss is zero, whereas a positive loss is attached to inflation outcomes outside the range of $[0, 2]$. The graphs in the figure can be interpreted as an index of the degree of dissatisfaction that the policy-maker experiences as the inflation rate varies. Parameter a is the exponential weight attached to downside deviations from zero, while parameter b is the exponential weight given to upside deviations from 2%. Since these

[14]To the extent that the policy-maker is also concerned about fluctuations in output around potential, it will be straightforward to augment the family of loss functions with an output gap term, like in the vast literature on flexible inflation targeting; see, e.g., Svensson (1997).

parameters need not necessarily be equal, the policy-maker's preferences can be asymmetric with respect to downside and upside risks.

Given that the policy-maker wishes to minimise the expected loss, his preferences are weighted by the probabilities attached to alternative inflation outcomes. When parameter a is zero, the policy-maker only cares about the probability of deflation and not about the severity of the deflation outcome. This is reflected in the loss being constant for all inflation outcomes below zero. Similarly, if parameter b is zero, the policy-maker only cares about the probability of excess inflation and not about the extent to which inflation exceeds 2%. These two cases correspond to the risk analysis undertaken in the previous section with its focus on deflation and excess inflation probabilities. The larger the parameters a and b, the more dissatisfied the policy-maker becomes as inflation exceeds the thresholds by a given amount. Likewise, the parameters a and b may be regarded as the degree of risk aversion on the part of a policy-maker who is concerned about deflation and excess inflation events. For the assumed family of loss functions, $a = 1$ ($b = 1$) implies risk neutrality with respect to deflation (excess inflation), risk-seeking behaviour is implied by values less than unity, and risk averse behaviour follows from values greater than unity.

Formally, let L be the lower bound and U the upper bound for which the loss is zero whenever inflation falls between L and U. With π denoting inflation, the downside risk is measured as the expected loss of deflation given that inflation is below the threshold L times the probability that this event occurs,

$$DR(L, a) \quad = \quad -\,\mathrm{E}[(L - \pi)^a | \pi < L] \cdot \Pr[\pi < L],$$

while the upside risk is given by the expected loss of excess inflation given that inflation is above the threshold U times the probability that this event occurs,

$$UR(U, b) \quad = \quad \mathrm{E}[(\pi - U)^b | \pi > U] \cdot \Pr[\pi > U].$$

With the adopted convention of defining downside risks as a negative number and upside risks as a positive number, the overall expected loss is given by

$$\mathrm{E}[Loss(L, U, a, b)] \quad = \quad -\,\omega\, DR(L, a) + (1 - \omega)\, UR(U, b),$$

where the parameter ω is the weight on downside risks relative to upside risks in the underlying loss function.

Yet as pointed out by Kilian and Manganelli (2007), in a discussion of risks it seems natural to focus on the balance of the upside and downside risks, as opposed to the overall extent of the risks. Recognising that the underlying loss function establishes a link between the optimal level of inflation from the policy-maker's point of view and the balance of the upside and downside risks, Kilian and Manganelli show that to this effect a measure of the *balance of risks* can be derived under optimality arguments as a weighted average of the change in the quantified upside and downside risks,[15]

$$RB(L,U,a,b) = \omega\, a\, DR(L,a-1) + (1-\omega)\, b\, UR(U,b-1).$$

Accordingly, the balance of risks may remain unchanged even though both downside and upside risks are assessed as having risen.[16]

In the following, the computation of all balance of risks measures will be based on the assumption that the weight ω given to losses from deflation relative to losses from excess inflation is equal to 0.5 (as was assumed in the construction of the graphs in Figure 2).

Benchmark results

The first column of Table 3 shows the evolution of the balance of deflation and excess inflation risks for the forecast vintages from December 2008 to December 2011 assuming a quadratic loss function ($a = b = 2$).[17] This balance of risk measure, normalised by its steady-state value, will serve as our benchmark measure and is equal to the probability-weighted sum of the mean of deflation and the mean of excess inflation conditional on the events that annual inflation has been either below zero ($L = 0$) or above 2% ($U = 2$) for at least 4 consecutive quarters (see the second and the fourth column in the table).[18] A value of zero therefore implies that upside and downside risks are balanced relative to the steady state, while negative (positive) values imply that downside (upside) risks dominate. Accordingly, our benchmark risk balance measure suggests that downside risks were markedly greater than upside risks for the March and June 2009 forecast vintages, followed by a gradual re-balancing of these risks until summer 2011, when the risk balance started to turn negative again on account of the worsening of the euro area sovereign debt crisis.

The bottom line in Table 3 provides the values of the deflation and excess inflation means based on the NAWM's predictive distribution for inflation initialised in the model's steady state. The steady-state deflation mean of -1% is higher than the average mean of -2% that is obtained for the predictive distributions of inflation associated with the 13 forecast

[15]Kilian and Manganelli (2007) argue that changes in the balance of risk measure should trigger a policy response. To the extent that we use the risk balance as a means for evaluating the evolution of risks to price stability ex post, we do not pursue this idea further. See also the discussion in footnote 6.

[16]Notice that the risk balance measure is only defined for risk aversion on the part of the policy-maker, i.e. when $a, b > 1$.

[17]For an earlier application of balance of risk measures based on a quadratic loss function, see Smets and Wouters (2004), who study the forecasting properties of a DSGE model for the euro area.

vintages from December 2008 to December 2011. By contrast, the average excess inflation mean remains close to the steady-state value of 3.2%. Consequently, the steady-state risk balance is higher than the risk balance measures for the individual forecast vintages, as reflected in the negative values of the normalised risk balance measure in the first column of the table.

The evolution of the risk balance measure in Table 3 displays a pattern which is similar to the pattern of the deflation and excess inflation probabilities in Table 1. This reflects the fact that the time profile of the risk balance is primarily determined by the time profiles for the deflation and excess inflation probabilities. In particular, while the deflation mean falls from -1.7% for the December 2008 forecast vintage to, on average, around -2% for the forecast vintages in 2009, the deflation probability increases from around 4% to above 12.5% on average. Furthermore, while the deflation probability diminishes from the September 2009 forecast vintage onwards, except for the renewed up-tick in late 2011, the deflation mean remains relatively stable over this period, with some further, albeit temporary declines in summer 2010 and autumn 2011 because of a stronger downward skew of the predictive distributions for inflation on account of the heightened lower bound incidence in 2010 and late 2011. This pattern contrasts with the finding that the excess inflation mean stays fairly constant over all forecast vintages.

The third and the fifth column in Table 3 show the variances of deflation and excess inflation, conditional on the respective deflation and excess inflation events. These variances form the basis for alternative measures of the risk balance that assume higher degrees of risk aversion with respect to deflation and excess inflation events. We turn to such measures in the next section. Here we note that the time profile of the deflation variance resembles closely the time profile of the deflation mean, with elevated levels assumed in early 2009, mid 2010 and late 2011. The fluctuations in the excess inflation variance are less pronounced, like for the excess inflation mean.

Sensitivity analysis

The benchmark risk balance measure which is used to determine the values reported in Table 3 relies on particular upper and lower bounds defining the deflation and excess inflation events ($L = 0$, $U = 2$). Moreover, the benchmark measure is based on particular values for the parameters that represent the degrees of risk aversion used to quantify the upside and downside risks to price stability ($a = b = 2$). To study its robustness to changes in these parameters, five alternative risk balance measures have been considered.

The findings from this sensitivity analysis are summarised in Table 4. First, the risk balance measure is recomputed under the assumption that the bound defining a deflation event is increased from zero to 1% ($L = 1$), possibly reflecting some margin that accounts for a bias in inflation measurement, while the bound for excess inflation remains at 2%. The results are reported in the panel of the table titled "Higher deflation bound". Second, only the bound defining inflation is increased from 2% to 3% ($U = 3$), while the deflation bound remains unchanged at zero; this panel is labelled by "Higher inflation bound". Third, the "Higher deflation aversion" panel reflects a higher aversion to downside risks ($a = 3$), while the aversion to upside risks remains equal to the one used in the benchmark case. Fourth, for the panel "Higher inflation aversion" the aversion to upside risks is increased ($b = 3$), whereas the aversion to downside risks remains unchanged. Finally, for the "Higher deflation and inflation aversion" panel, the aversion to both downside and upside risks is proportionally increased ($a = b = 3$). The three cases with higher deflation and/or inflation aversion are based on the bounds from the benchmark case, i.e. with a deflation bound of zero and an excess inflation bound of 2%.

Overall, the changes to the risk balance measure do not qualitatively change the time series pattern of the balance of deflation and excess inflation risks. In particular, treating each measure as an index, all indices confirm that deflation risks were most sizeable for the March and June 2009 forecast vintages and that excess inflation risks have thereafter become gradually more important before receding again in late 2011. The only measures that deviate from this finding concern the two cases where the degree of deflation aversion is increased. For the March and June 2010 vintages, these risk balance measures temporarily decrease further reflecting a large increase in the variance of deflation relative to the December 2009 vintage; see the third column in Table 3. The growing deflation variance is, as already noted above, closely linked to the development of the lower bound incidence which increases from 17.7% in the December 2009 vintage to respectively 19.1% and 24.7% in the March and June 2010 vintages; see the far right column in Table 1.

4 Risks to price stability and forward guidance

Once interest rates have reached their lower bound, different non-standard monetary policy measures can be implemented. Amongst these non-standard measures, *forward guidance* regarding the path of future short-term nominal interest rates amounts to a commitment on the part of the monetary policy-maker to keep nominal interest rates low for longer to ensure a faster return of the economy to macroeconomic stability. The theoretical underpinnings of forward guidance are well understood: It revolves around the idea of influencing the private sector's interest rate and inflation expectations in an attempt to provide additional stimulus to the economy through lower expected future real interest rates.[19]

Typically, studies have analysed the effects of forward guidance once short-term nominal interest rates have reached the zero lower bound following a sequence of recessionary shocks and often in a deterministic setting.[20] Here, we again employ stochastic simulations using the NAWM to illustrate that the anticipation of the provision of forward guidance in the future can already be conducive to restoring price stability even though the interest rate has not yet reached the zero lower bound, which is arguably the situation in the euro area over our evaluation period. The potency of the mere *possibility* of forward guidance reflects the fact that private sector's expectations incorporate the knowledge that the scope for *future* cuts in nominal interest rates is limited once they are close to zero, without having necessarily reached the zero lower bound.

Table 5 provides an illustration of the possible effects of providing forward guidance concerning the future path of the short-term nominal interest rate against the background of the economic conditions that prevailed in December 2011.[21] First, we recall as a point of reference the results of the NAWM-based assessment of risks to price stability. When comparing the deflation and excess inflation risks for this forecast vintage (line 1) to those obtained from the model's steady-state distribution (line 5), it can be seen that the deflation risk exceeds the steady-state value by about 5 percentage points, while the excess inflation risk stays below the steady-state value by a somewhat smaller amount. The (benchmark) risk balance measure is tilted to the downside and stands at -0.7.

An important factor in explaining the negative risk balance is the heightened value of the lower-bound incidence which amounts to 29.0%, compared with 0.3% for the model's steady-state predictive distribution. This record-high value of the lower-bound incidence reflects the historically low level of short-term nominal interest rates that markets expected to prevail over the horizon of the December 2011 forecast vintage. It implies that monetary policy is likely to be increasingly often constrained in its ability to offset any further recessionary and deflationary shocks that may occur over the forecast horizon by adjusting its interest rate instrument.

[19]See, among others, Eggertsson and Woodford (2003), Adam and Billi (2006), Nakov (2008), Walsh (2009) and Woodford (2012).

[20]For a discussion of possible limitations on the effectiveness of forward guidance following severe recessions see Levin, López-Salido, Nelson and Yun (2010).

[21]While the ECB has refrained from providing forward guidance, it implemented a number of other non-standard measures; see footnote 3. In our analysis we do not explicitly consider those measures, or anticipations thereof, but rather assume that they are reflected in the baseline forecast path around which we conduct the model-based simulations.

In the NAWM-based simulations, forward guidance is implemented as a *conditional commitment* by the monetary policy-maker to keep the short-term nominal interest rate low for longer than prescribed by the model's estimated Taylor-type interest rate rule (see Appendix A for details) in the presence of the zero lower bound. Specifically, the conditional commitment foresees to keep the short-term nominal interest rate at the lower bound for a certain number of additional quarters whenever the lower bound is hit, over and above the number of quarters for which the interest rate is constrained in the absence of the conditional commitment. The commitment is conditioned on the outlook for inflation and economic activity through the implied interest rate path; and it is revisited each quarter in view of the arrival of new shocks.[22]

As shown in Table 5, incrementally increasing the number of additional quarters the interest rate is expected to remain at the lower bound—from the baseline case with no commitment to the cases with a 1 and 2-quarter conditional commitment—succeeds in tilting the risk balance upwards to -0.6 and -0.3, respectively (see line 2 and line 3 in the table). Interestingly, if the conditional commitment is extended further to 3 quarters (line 4), the risk balance turns positive, and vastly so. Lengthening the duration of the conditional commitment beyond 2 quarters has such a strong impact through its influence on private sector expectations that heightened inflationary pressures emerge, with the probability of excess inflation exceeding 40%. This value is considerably higher than the steady-state probability of about 29%. Notice that the incidence of the short-term interest rate hitting the lower bound turns out to be lower ex post.

Figure 3 shows the mean and the 70% and 90% confidence bands of the NAWM-based predictive distributions of consumer price inflation and real GDP growth for the December 2011 forecast vintage, both for the case with no and for the three cases with the 1, 2 and 3-quarter conditional commitment. In the case with no conditional commitment (see panel A in the figure), the predictive distributions are markedly skewed to the downside from the middle of 2012 onwards. As a result, their means depart from the baseline paths and lie increasingly below the latter over the outer years of the forecast horizon. This is due to the fact that the reaction of monetary policy to new recessionary and deflationary shocks over the forecast horizon is increasingly often constrained by the zero lower bound. By contrast, in the cases with the 1, 2 and 3-quarter conditional commitment (panels B

[22] On the whole, the proposed conditional commitment to keep the interest rate low for a certain number of additional quarters seems more easy to implement in practice than a proposal by Reifschneider and Williams (2000), which features a conditional commitment to undo the (unobservable) "interest rate gap" corresponding to the cumulated short-fall of the notional interest rate prescribed by an interest rate rule without having imposed the lower bound constraint from the interest rate which respects the constraint.

to D) the predictive distributions for consumer price inflation and real GDP growth are progressively shifted upward, with the mean of the distributions broadly aligned with the baseline forecast under the 2-quarter commitment and increasingly exceeding the baseline under the 3-quarter commitment.[23]

Table 6 reports the mean effects of the conditional commitment to keep the interest rate low for longer, computed as the deviation from the mean of the predictive distributions for the December 2011 baseline forecast with no commitment. It can be seen that the effect of the conditional commitment of keeping the interest rate at the lower bound for longer is increasing non-linearly with the duration of the commitment. For example, the incremental effect of lengthening the duration of the commitment from 2 to 3 quarters on the mean of inflation in 2013 amounts to almost 1.2 percentage points, compared to a 0.4 percentage-point effect of extending the commitment from 1 to 2 quarters. The key factor behind this result is the acceleration in the build-up of medium-term inflation expectations. By contrast, medium-term interest-rate expectations are virtually unaffected. This reflects the fact that current as well as expected interest rates are endogenous variables which adjust to the improved outlook, including for inflation, instantaneously.[24]

All in all, our findings suggest that, for practical policy-making purposes, it will be important to carefully calibrate the length of the horizon over which a conditional commitment is made. Indeed, if not carefully designed, forward guidance in the form of a conditional commitment may, primarily through its impact on inflation expectations, create higher inflationary momentum than desired, leading to upside risk to price stability over the medium term. In this respect, the uniform length of the commitment horizon assumed in the model simulations is arguably not optimal. Rather than linking it in a simple manner to the incidence that the zero lower bound is binding, one may want to make it dependent on the severity of the underlying deflationary and/or recessionary events. To this effect, the measure of the balance of risks to price stability studied in this paper may serve as one possible guidepost for providing forward guidance once short-term nominal interest rates are at the zero lower bound.

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[23] As regards the predictive distributions for the short-term interest rate, differences are hardly discernible; see Appendix Figure B.

[24] Relevant to these findings, Carlstrom, Fuerst and Paustian (2012) show that in prototype New Keynesian models pegging the short-term nominal interest rate—tantamount to credibly announcing that it will remain at the zero lower bound for longer—can result in responses of macroeconomic variables that are surprisingly large. Using simulations with an estimated medium-size New Keynesian model like the NAWM, Del Negro, Giannoni and Patterson (2012) explain such behaviour by the model's tendency to predict an excessive response of the *long-term* nominal interest rate, compared to what has been measured in the data following, e.g., statements on forward guidance by the Federal Reserve's Federal Open Market Committee.

5 Summary and conclusions

In this paper, we have studied the evolution of the risks to price stability in the euro area in the aftermath of the financial crisis of 2008-09. To this end, we have employed model-based stochastic simulations to characterise the profound uncertainties and risks that surrounded the outlook for inflation in the euro area in real time. A formal measure of the balance of risks, which is based on policy-makers' preferences about inflation outcomes and takes the severity of the prevailing risks into account, suggests that downside risks to price stability were considerably greater than upside risks during the first half of 2009. After a drawn-out re-balancing of risks, the risk balance started to turn negative again in the second half of 2011 due to the re-intensification of the crisis on account of elevated tensions in euro area sovereign debt markets. Our analysis demonstrates that the lower bound on nominal interest rates has induced a noticeable downward bias to the risk balance throughout the crisis period because of the implied amplification of deflation risks.

While our analysis of the evolution of risks to price stability offers a narrative of the consequences of the financial crisis for the inflation outlook in real time, the employed methodology of stochastic simulations has also been used to examine the effects of counterfactual policy measures. In particular, we have examined the effectiveness of providing forward guidance concerning the future path of the short-term nominal interest rate as a means to delivering additional stimulus in a situation where nominal interest rates are close to zero and where downside risks to price stability prevail. We show that forward guidance imparts the intended stimulus and is successful in reducing the prevailing downside risks. Yet if not carefully designed, it may, through its impact on inflation expectations, actually give rise to upside risks to price stability over the medium term.

We conclude by arguing that the model-based measure of the balance of risks to price stability studied in this paper may serve as a helpful means for communicating with the public about the general uncertainties and risks surrounding any given baseline forecast, over and above the use of scenario analyses that highlight the consequences of specific shocks and events over the forecast horizon. Moreover, to the extent that the balance of risk measure is derived from the preferences of policy-makers that are concerned about inflation, it establishes a link between desirable levels of inflation from the policy-makers' point of view and the balance of upside and downside risks ro price stability. Accordingly, the risk measure itself may become a guidepost for policy-making.

References

Adam, K. and R. Billi, 2006, "Optimal Monetary Policy under Commitment with a Zero Bound on Nominal Interest Rates", *Journal of Money, Credit, and Banking*, 38, 1877-1905.

Anderson, G. S., 1987, "A Procedure for Differentiating Perfect-Foresight-Model Reduced-Form Coefficients", *Journal of Economic Dynamics and Control*, 11, 465-481.

Anderson, G. S. and G. R. Moore, 1985, "A Linear Algebraic Procedure for Solving Linear Perfect Foresight Models", *Economics Letters*, 17, 247-252.

Blanchard, O. J. and C. Kahn, 1980, "The Solution of Linear Difference Models under Rational Expectations", *Econometrica*, 48, 1305-1311.

Bodenstein, M., J. Hebden and R. Nunes, 2012, "Imperfect Credibility and the Zero Lower Bound", *Journal of Monetary Economics*, 59, 135-149.

Boucekkine, R., 1995, "An Alternative Methodology for Solving Nonlinear Forward-Looking Models", *Journal of Economic Dynamics and Control*, 19, 711-734.

Carlstrom, C., T. Fuerst, and M. Paustian, 2012, "Inflation and Output in New Keynesian Models with a Transient Interest Rate Peg", Working Paper No. 12/34, Federal Reserve Bank of Cleveland.

Christoffel, K., G. Coenen and A. Warne, 2008, "The New Area-Wide Model of the Euro Area: A Micro-Founded Open-Economy Model for Forecasting and Policy Analysis", ECB Working Paper No. 944, European Central Bank.

Chung, H., J.-P. Laforte, D. Reifschneider and J. C. Williams, 2011, "Have We Underestimated the Likelihood and Severity of Zero Lower Bound Events?", FRBSF Working Paper Series, 2011-01, Federal Reserve Bank of San Francisco.

Clinton, K., R. Garcia-Saltos, M. Johnson, O. Kamenik and D. Laxton, 2010, "International Deflation Risks under Alternative Macroeconomic Policies", *Journal of the Japanese and International Economies*, 24, 140-177.

Coenen, G., A. Orphanides and V. Wieland, 2004, "Price Stability and Monetary Policy Effectiveness when Nominal Interest Rates are Bounded at Zero", *B.E. Journal of Macroeconomics: Advances in Macroeconomics*, 4, Article 1.

Coenen, G., R. Straub and M. Trabandt, 2012, "Fiscal Policy and the Great Recession in the Euro Area", *American Economic Review, Papers and Proceedings*, 102, 71-76.

Coenen, G., R. Straub and M. Trabandt, 2013, "Gauging the Effects of Fiscal Stimulus Packages in the Euro Area", *Journal of Economic Dynamics and Control*, 37, 367-386.

Del Negro, M., M. Giannoni and C. Patterson, 2012, "The Forward Guidance Puzzle", FRBNY Staff Report No. 574, Federal Reserve Bank of New York.

ECB, 2010a, "The ECB's Response to the Crisis", *Monthly Bulletin*, European Central Bank, October.

ECB, 2010b, "The Effectiveness of Euro Area Fiscal Policies", *Monthly Bulletin*, European Central Bank, July.

ECB, 2012, "ECB Staff Macroeconomic Projections for the Euro Area", *Monthly Bulletin*, European Central Bank, September.

Eggertsson, G. B. and M. Woodford, 2003, "The Zero Bound on Interest Rates and Optimal Monetary Policy", *Brookings Papers on Economic Activity*, 34, 139-211.

European Commission, 2009, "Public Finances in EMU", *European Economy*, 5/2009, European Commission.

Fair, R. and J. B. Taylor, 1983, "Solution and Maximum Likelihood Estimation of Dynamic Nonlinear Rational Expectations Models", *Econometrica*, 51, 1169-1185.

Fishburn, P. C., 1977, "Mean-Risk Analysis with Risk Associated with Below-Target Returns", *American Economic Review*, 67, 116-126.

Holthausen, D. M., 1981, "A Risk-Return Model with Risk and Return Measured in Deviations from Target Returns", *American Economic Review*, 71, 182-188.

IMF, 2009, "Global Prospects and Policies", *World Economic Outlook*, International Monetary Fund, April.

Juillard, M., 1994, "DYNARE – A Program for the Resolution of Non-Linear Models with Forward-Looking Variables", Release 1.1, Manuscript, CEPREMAP.

Kilian, L. and S. Manganelli, 2007, "Quantifying the Risk of Deflation", *Journal of Money, Credit, and Banking*, 39, 561-590.

Laffargue, J.-P., 1990, "Résolution d'un Modèle Macroéconomique avec Anticipations Rationnelles", *Annales d'Economie et de Statistique*, 17, 97-119.

Levin, A., D. López-Salido, E. Nelson and T. Yun, 2010, "Limitations on the Effectiveness of Forward Guidance at the Zero Lower Bound", *International Journal of Central Banking*, 6, 143-189.

Machina, M. J. and M. Rothschild, 1987, "Risk", in J. Eatwell, M. Millgate and P. Newman (eds), *The New Palgrave Dictionary of Economics*, MacMillan, 203-206.

Nakov, A., 2008, "Optimal and Simple Monetary Policy Rules with Zero Floor on the Nominal Interest Rate", *International Journal of Central Banking*, 4, 73-128.

Orphanides, A. and V. Wieland, 2000, "Efficient Monetary Policy Design Near Price Stability", *Journal of the Japanese and International Economies*, 14, 327-365.

Reifschneider, D. and J. C. Williams, 2000, "Three Lessons for Monetary Policy in a Low-Inflation Era", *Journal of Money, Credit, and Banking*, 32, 936-966.

Smets, F. and R. Wouters, 2004, "Forecasting with a Bayesian DSGE Model: An Application to the Euro Area", *Journal of Common Market Studies*, 42, 841-867.

Smets, F. and R. Wouters, 2007, "Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach", *American Economic Review*, 97, 586-606.

Svensson, L.E.O., 1997, "Inflation Forecast Targeting: Implementing and Monitoring Inflation Targets", *European Economic Review*, 41, 1111-1146.

Walsh, C. E., 2009, "Using Monetary Policy to Stabilize Economic Activity", Presentation at the Federal Reserve Bank of Kansas City's Symposium on "Financial Stability and Macroeconomic Policy", Jackson Hole, Wyoming, August 20-22.

Warne, A., 2012, "YADA Manual – Computational Details", Manuscript, European Central Bank.

Williams, J. C., 2009, "Heeding Daedalus: Optimal Inflation and the Zero Lower Bound", *Brookings Papers on Economic Activity*, 40, 1-37.

Woodford, M., 2012, "Methods of Policy Accommodation at the Interest-Rate Lower Bound", Presentation at the Federal Reserve Bank of Kansas City's Symposium on "The Changing Policy Landscape", Jackson Hole, Wyoming, August 31-September 1.

A The New Area-Wide Model

The New Area-Wide Model (NAWM) is a micro-founded open-economy model of the euro area designed for use in the ECB/Eurosystem staff projections and for policy analysis; see Christoffel, Coenen and Warne (2008) for a detailed description. The development of the model has been guided by a principal consideration, namely to provide a comprehensive set of core projection variables, including a number of foreign variables, which, in the form of exogenous assumptions, play an important role in the staff projections. As a consequence, the size of the NAWM—compared with the well-known Smets and Wouters (2007) model—is rather large, and it is estimated on 18 macroeconomic time series.

The NAWM features four classes of economic agents: households, firms, a fiscal authority and a monetary authority. Households make optimal choices regarding their purchases of consumption and investment goods, the latter determining the economy-wide capital stock. They supply differentiated labour services in monopolistically competitive markets, they set wages as a mark-up over the marginal rate of substitution between consumption and leisure, and they trade in domestic and foreign bonds.

As regards firms, the NAWM distinguishes between domestic producers of tradable intermediate goods and domestic producers of three types of non-tradable final goods: a private consumption good, a private investment good, and a public consumption good. The intermediate-good firms use labour and capital services as inputs to produce differentiated goods, which are sold in monopolistically competitive markets domestically and abroad. Accordingly, they set different prices for domestic and foreign markets as a mark-up over their marginal costs. The final-good firms combine domestic and foreign intermediate goods in different proportions, acting as price takers in fully competitive markets. The foreign intermediate goods are imported from producers abroad, who set their prices in euro in monopolistically competitive markets, allowing for an incomplete exchange-rate pass-through. A foreign retail firm in turn combines the exported domestic intermediate goods, where aggregate export demand depends on total foreign demand.

Both households and firms face nominal and real frictions, which have been identified as important in generating empirically plausible dynamics. Real frictions are introduced via external habit formation in consumption, through generalised adjustment costs in investment, imports and exports, and through fixed cost in intermediate goods production. Nominal frictions arise from staggered price and wage-setting à la Calvo, along with (partial) dynamic indexation of price and wage contracts. In addition, there exist financial frictions in the form of domestic and external risk premia that enter the model as exogenous shocks. The domestic risk premium is interpretable as a financial intermediation premium.[25]

[25] The historical decomposition of the NAWM's observed variables into its structural shocks reveals that the domestic risk premium shock is amongst the most important shocks explaining the sharp drop in real GDP at the onset of the financial crisis. Moreover, the domestic risk premium shock is found to capture the adverse economic consequences of the sovereign debt crisis in the years 2010 and 2011 that resulted in a surge in sovereign yields and private sector financing costs.

The fiscal authority purchases the public consumption good, issues domestic bonds, and levies different types of distortionary taxes. Nevertheless, Ricardian equivalence holds because of the simplifying assumption that the fiscal authority's budget is balanced each period by means of lump-sum taxes. The monetary authority sets the short-term nominal interest rate according to a simple log-linear rule,

$$\widehat{r}_t \;=\; \phi_R\, \widehat{r}_{t-1} + (1-\phi_R)\, \phi_\Pi \widehat{\pi}_{C,t-1} + \phi_{\Delta\Pi}\left(\widehat{\pi}_{C,t} - \widehat{\pi}_{C,t-1}\right) + \phi_{\Delta Y}\left(\widehat{y}_t - \widehat{y}_{t-1}\right) + \widehat{\eta}_t^R,$$

where $\widehat{r}_t$ is the logarithmic deviation of the (gross) nominal interest rate from its steady-state value. Similarly, $\widehat{\pi}_{C,t}$ denotes the logarithmic deviation of (gross) quarter-on-quarter consumer price inflation $\Pi_{C,t}$ from the monetary authority's inflation objective $\bar{\Pi}$, while $\widehat{y}_t$ is the logarithmic deviation of aggregate output from the trend output level. $\widehat{\eta}_t^R$ is a serially uncorrelated shock to the nominal interest rate.

Finally, the NAWM is closed by a rest-of-the-world block, which is represented by an SVAR model determining a small set of foreign variables: foreign demand, foreign prices, the foreign interest rate, foreign competitors' export prices and the price of oil. The SVAR model does not feature spill-overs from the euro area, in line with the treatment of the foreign variables as exogenous assumptions in the staff projections.

The NAWM has been estimated with Bayesian methods and using times series for 18 macroeconomic variables which feature prominently in the projections: real GDP, private consumption, total investment, government consumption, extra-euro area exports and imports, the GDP deflator, the consumption deflator, the extra-euro area import deflator, total employment, nominal wages per head, the short-term nominal interest rate, the nominal effective exchange rate, foreign demand, foreign prices, the foreign interest rate, competitors export prices, and the price of oil. The estimation sample period ranges from 1985Q1 to 2006Q4 (using the period 1980Q2 to 1984Q4 as training sample). The estimation involves obtaining the posterior distribution of the model's parameters based on its state-space representation using the Kalman filter.[26]

B Construction of baseline forecasts

The forecast vintages are dated December 2008 until December 2011 and they have been constructed by combining the quarterly Area-Wide Model (AWM) database maintained at the ECB with the quarterly Consensus Forecasts (CF) vintages released by Consensus Economics. The AWM database is updated annually with a cut-off date for a new update in early August each year. Each annual update contains euro area data up to Q4 for the previous year. The CF vintages are updated quarterly.

[26] For the estimation of the NAWM, we have used YADA, a MATLAB programme for Bayesian estimation and evaluation of DSGE models; see Warne (2012).

The historical data for the constructed quarterly forecast vintages are all based on the AWM database updates. Therefore they only reflect annual revisions. The historical data in the CF vintages from September and December of a given year contain data for Q3 and Q4 of real GDP, real private consumption, and consumer prices for the previous year. Since these data are more recent than the AWM data available at the same point in time, the CF data are used in the September and December forecast vintages. For all CF vintages further historical data and forecasts are provided for these variables up to a total of 12 quarters. This means that the September and December vintages have such data from Q3 of the previous year until Q2 two years ahead. E.g., for the December 2008 CF vintage the forecast data cover the sample 2008Q3-2010Q2. For the March and June vintages the CF data cover Q1 for the previous year until Q4 for the next year.

The first quarter of the ECB/Eurosystem staff projections is given by the projection/vintage date (e.g., 2008Q4 for the December 2008 projection exercise), while the final quarter of the projections is always Q4 two years ahead.[27] This means that there are 12 projection quarters for the March vintage, 11 for the June vintage, 10 for the September vintage, and 9 for the December vintage. The forecast vintages in this paper use the same horizon as the staff projections. Compared with the end date for the ECB staff projections, this means that the March and June CF vintages have missing data in the last four quarters of the forecast sample, while the September and December vintages have missing data in the last two quarters of the forecast sample.

Furthermore, the AWM database series for the short-term nominal interest rate (corresponding to the EURIBOR) has been extended to the end of the forecast horizon by applying the methodology used by ECB/Eurosystem staff, with market expectations derived from futures rates (see, e.g., ECB, 2012) and using a cut-off date aligned with the survey date of the CF vintage. The EONIA forecasts have likewise been calculated using a similar methodology based on swap rates.

For real GDP and real private consumption quarterly growth rates are provided in the CF vintages and these rates have been applied to the levels data from the AWM database to obtain CF consistent levels data for these two variables. The missing data for real GDP and private consumption have been estimated by applying an ARIMA(0,1,1) model with a constant to the log-levels of these variables. For consumer prices the CF vintages provide only annual growth rates. These annual rates have been applied to the HICP variable of the AWM database. The resulting HICP series is likewise extended using an ARIMA(0,4,1,) model with a constant for the log-levels and accounting for seasonality. The resulting growth rates have been applied to extend the series for the private consumption deflator over the historical and the forecast sample.

[27] Even though the staff prepares quarterly projections until Q4 two years ahead, the ECB only publishes, in the form of ranges, annual projections of a restricted set of variables for the current year and one year ahead, except for the publication of the December projection exercises which cover two-year ahead projections.

For the remaining variables of the NAWM there are historical data for each forecast vintage until the end of the year prior to the vintage date for the September and the December vintages, and until the end of two years prior to the vintage date for the March and June vintages. For example, for the December 2009 vintage there are AWM data on wages until 2008Q4. This means that there are missing data for the historical sample (up to 2009Q3). Rather than treating these data points as missing in the assessments of risks to price stability, the missing data are replaced with estimates via the Kalman smoother based on the state-space representation of the NAWM and using only the historical sample of the forecast vintage.

C Solution and simulation methods

In preparation for the stochastic simulations, we first computed for each baseline forecast vintage the structural shocks and the state variables of the NAWM for the historical sample extended with the baseline forecast. Since the non-negativity constraint for nominal interest rates was never binding in the extended sample, we obtained the structural shocks and states by solving the NAWM for its reduced form using the AIM implementation (Anderson and Moore, 1985, and Anderson, 1987) of the Blanchard and Kahn (1980) method for solving linear rational expectations models and by applying the Kalman filter to its (log-)linear state-space representation.

Based on the population covariance matrix of the structural shocks and the conditional covariance matrix of the states at the origin of the baseline forecast horizon, we then generated for each forecast vintage 5,000 sequences of artificial normally-distributed shocks with a sample length corresponding to the baseline forecast horizon and 5,000 realisations of the states.[28] We added the sequences of the artificial shocks (except for the shocks to the NAWM's interest rate rule which we set to zero) to the sequence of shocks computed over the baseline forecast horizon and used the resulting sequences of shocks to conduct stochastic simulations, while imposing the zero lower bound constraint on nominal interest rates.[29] If it were not for this non-linearity, we could use the linear state-space representation of the NAWM to compute the predictive distributions of the endogenous variables of interest without having to resort to stochastic simulations.

[28] That is, we restrict our analysis to a fixed set of parameters, namely the posterior mode estimates of the NAWM's structural parameters. Accounting for parameter uncertainty by drawing from the posterior distribution of the structural parameters would have been computationally too burdensome.

[29] To ensure stability of the model in the presence of the zero lower bound constraint, fiscal policy is assumed to boost aggregate demand to rescue the economy from falling into a deflationary spiral, if deflation becomes so severe that the lower bound restricts the real interest rate at a level high enough to induce a growing aggregate demand imbalance. An alternative approach to ensuring stability is to concentrate on other channels of the monetary transmission mechanism that may continue to operate even when the interest rate channel is ineffective. E.g., Orphanides and Wieland (2000) concentrate on the aggressive expansion of the monetary base during episodes of zero interest rates to exploit direct quantity effects such as a portfolio-balance effect.

We simulate the non-linear model using a computationally efficient algorithm which is implemented in TROLL and based on work by Laffargue (1990), Juillard (1994) and Boucekkine (1995).[30] It is related to the Fair and Taylor (1983) extended-path algorithm. In the simulations, the lower bound constraint also applies to the expectations of future interest rates. A limitation of the algorithm is that the expectations of economic agents are computed under the counterfactual assumption that *certainty equivalence* holds in the non-linear model being simulated. This means, when solving for the dynamic path of the endogenous variables from a given period onwards, the algorithm sets future shocks equal to their expected value of zero. Thus the variance of future shocks has no bearing on the formation of expectations and, hence, on current conditions. This would be correct in a linear model. However once we introduce the zero lower bound on nominal interest rates into the model, we are able to show that the variance of future shocks ought to be expected to introduce a small bias in the average levels of various variables, including importantly, interest rates. To be clear, we should emphasise that the variance of shocks has both a direct and an indirect effect on the results. The direct effect is that a greater variance of shocks implies that the zero lower bound on nominal interest rates binds with greater frequency, the indirect effect is that all agents should be taking this effect of the variance into account when they form their expectations. The simulation algorithm captures the direct effect but not the indirect one.

There are other solution algorithms for non-linear rational expectations models that do not impose certainty equivalence. But these alternative algorithms would be prohibitively costly to use with the NAWM, which has more than eighty state variables. Even with the algorithm we are using, stochastic analysis of non-linear rational expectations models with a large number of state variables remains fairly costly in terms of computational effort.

[30]TROLL is an integrated econometric modelling and time series management tool used by many central banks and international organisations.

Table 1: Gauging risks to price stability and the lower bound incidence.

	Risks to price stability		Lower bound incidence
	Deflation	Excess inflation	
December '08	4.4	15.3	6.0
March '09	13.9	11.6	15.9
June '09	14.8	9.8	11.0
September '09	12.2	10.1	16.5
December '09	9.2	9.3	17.7
March '10	11.1	12.9	19.1
June '10	10.5	15.8	24.7
September '10	8.0	18.8	22.4
December '10	5.6	19.8	19.0
March '11	4.2	30.7	8.1
June '11	3.6	33.5	9.2
September '11	7.3	23.9	25.2
December '11	6.8	24.6	29.0
Steady state	1.5	28.7	0.3

Note: This table describes the evolution of risks to price stability and of the importance of the lower bound constraint for short-term nominal interest rates over the period from December '08 to December '11. The deflation (excess inflation) risk corresponds to the probability of annual inflation being below zero (above 2%) for at least 4 consecutive quarters, expressed in percent. The lower bound incidence is equal to the probability that the short-term nominal interest rate is constrained by its lower bound, in percent. The risk measures and the lower bound incidence are based on the NAWM's predictive distributions for annual inflation and the short-term nominal interest rate which have been constructed around successive Consensus forecast vintages. The steady-state values are calculated from the predictive distributions for inflation and the nominal interest rate initialised at the model's steady state and expressed as averages over the different lengths of the forecast horizons within a calendar year. In the NAWM, the short-term nominal interest rate corresponds to the 3-month EURIBOR. The lower bound constraint is imposed at interest rate levels between 30 and 70 basis points, reflecting the average spread between the EURIBOR and the EONIA over the horizon of the respective Consensus forecast vintage.

Table 2: Gauging risks to price stability and the lower bound incidence in 2011.

	Risks to price stability		Lower bound incidence
	Deflation	Excess inflation	
March ’09	16.3	18.8	11.9
June ’09	14.8	15.7	6.5
September ’09	14.0	15.4	10.8
December ’09	12.5	12.9	11.8
March ’10	9.7	10.9	18.3
June ’10	4.3	13.3	28.0
September ’10	1.2	19.2	25.0
December ’10	0.1	19.1	21.2
March ’11	0.0	48.4	7.4

Note: See Table 1.

Table 3: The balance of risks to price stability and additional risk measures.

	Risk balance [L=0; U=2; a=2; b=2]	Deflation risk		Excess inflation risk	
		Mean	Variance	Mean	Variance
December '08	-0.7	-1.7	2.9	3.1	0.7
March '09	-1.6	-2.5	6.4	3.3	0.7
June '09	-1.5	-1.9	3.7	3.2	0.6
September '09	-1.3	-1.8	2.9	3.2	0.7
December '09	-1.2	-1.9	2.7	3.0	0.6
March '10	-1.3	-2.2	4.0	3.2	0.7
June '10	-1.3	-2.6	5.5	3.2	0.6
September '10	-1.0	-2.4	3.9	3.1	0.6
December '10	-0.7	-1.9	2.7	3.0	0.6
March '11	-0.2	-1.8	2.3	3.2	0.7
June '11	0.0	-1.9	2.8	3.2	0.6
September '11	-0.7	-2.4	4.2	3.1	0.5
December '11	-0.7	-2.3	3.8	3.1	0.5
Steady state	0.0	-1.0	0.5	3.2	0.7

Note: The risk balance is calculated from the predictive distribution of annual inflation as the probability-weighted mean of deflation and excess inflation, conditional on the respective deflation and excess inflation event, and normalised by its steady-state value. The upper and lower bounds defining the deflation and excess inflation events (L and U) are zero and 2%, respectively. The degrees of risk aversion assumed to quantify the deflation and excess inflation risks (a and b) are equal to 2, corresponding to a quadratic loss function on the part of the policy-maker. The steady-state means and variances are calculated from the predictive distribution of annual inflation initialised at the model's steady state, conditional on the event of interest, and expressed as averages over the different lengths of the forecast horizons.

Table 4: The sensitivity of the balance of risks to price stability.

	Benchmark [L=0; U=2; a=2; b=2]	Higher deflation bound [L=0; U=3; a=2; b=2]	Higher inflation bound [L=1; U=2; a=2; b=2]
December '08	-0.7	-1.2	-1.9
March '09	-1.6	-3.3	-5.9
June '09	-1.5	-3.1	-5.3
September '09	-1.3	-2.8	-4.5
December '09	-1.2	-2.6	-4.1
March '10	-1.3	-2.6	-4.3
June '10	-1.3	-2.4	-4.9
September '10	-1.0	-1.8	-3.7
December '10	-0.7	-1.3	-2.5
March '11	-0.2	-0.3	-0.9
June '11	0.0	-0.1	-0.6
September '11	-0.7	-1.4	-3.2
December '11	-0.7	-1.3	-3.2

	Higher deflation aversion [L=0; U=2; a=3; b=2]	Higher inflation aversion [L=0; U=2; a=2; b=3]	Higher deflation and inflation aversion [L=0; U=2; a=3; b=3]
December '08	-1.8	-0.5	-0.9
March '09	-9.2	-0.9	-3.4
June '09	-5.9	-1.0	-2.5
September '09	-4.4	-0.9	-2.0
December '09	-3.6	-0.9	-1.8
March '10	-5.3	-0.8	-2.1
June '10	-6.7	-0.8	-2.6
September '10	-4.0	-0.6	-1.7
December '10	-2.1	-0.5	-1.1
March '11	-0.9	-0.1	-0.4
June '11	-0.8	0.1	-0.2
September '11	-3.8	-0.5	-1.5
December '11	-3.3	-0.5	-1.4

Note: See Table 3. The benchmark case is computed from a deflation bound (L) of zero and an excess inflation bound (U) of 2%, with deflation and inflation aversion parameters (a and b) equal to 2. When the deflation (excess inflation) bound is higher, it is equal to 1% (3%). The cases with higher deflation and/or inflation aversion are based on increasing one or both of the aversion parameters from 2 to 3.

Table 5: Gauging risks to price stability under a conditional commitment to keep nominal interest rates low for longer, December '11.

	Risks to price stability		Risk balance	Lower bound incidence
	Deflation	Excess inflation		
December '11	6.8	24.6	-0.7	29.0
Interest rate kept at lower bound for:				
1 additional quarter	6.1	25.0	-0.6	28.9
2 additional quarters	3.4	27.1	-0.3	28.3
3 additional quarters	0.1	41.2	0.9	26.2
Steady state	1.5	28.7	0.0	0.3

Note: See Tables 1 and 3. The conditional commitment foresees to keep the short-term nominal interest rate at the lower bound for a certain number of additional quarters whenever the interest rate is constrained by the lower bound, over and above the number of quarters in the absence of the conditional commitment. The lower bound is imposed at an interest rate level of 60 basis points, reflecting the average spread between the EURIBOR and the EONIA over the horizon of the December '11 forecast vintage.

Table 6: Assessing the mean effects of a conditional commitment to keep nominal interest rates low for longer, December '11.

	Consumer price inflation			Real GDP growth		
	2011	2012	2013	2011	2012	2013
Interest rate kept at lower bound for:						
1 additional quarter	0.00	0.03	0.11	0.00	0.11	0.16
2 additional quarters	0.00	0.15	0.49	0.01	0.48	0.68
3 additional quarters	0.00	0.55	1.66	0.02	1.75	2.15

	2-year nominal interest rate			2-year inflation expectations		
	2011	2012	2013	2011	2012	2013
Interest rate kept at lower bound for:						
1 additional quarter	-0.00	-0.01	-0.01	0.00	0.05	0.10
2 additional quarters	-0.00	-0.01	-0.02	0.00	0.24	0.43
3 additional quarters	-0.00	-0.03	0.01	0.01	0.87	1.36

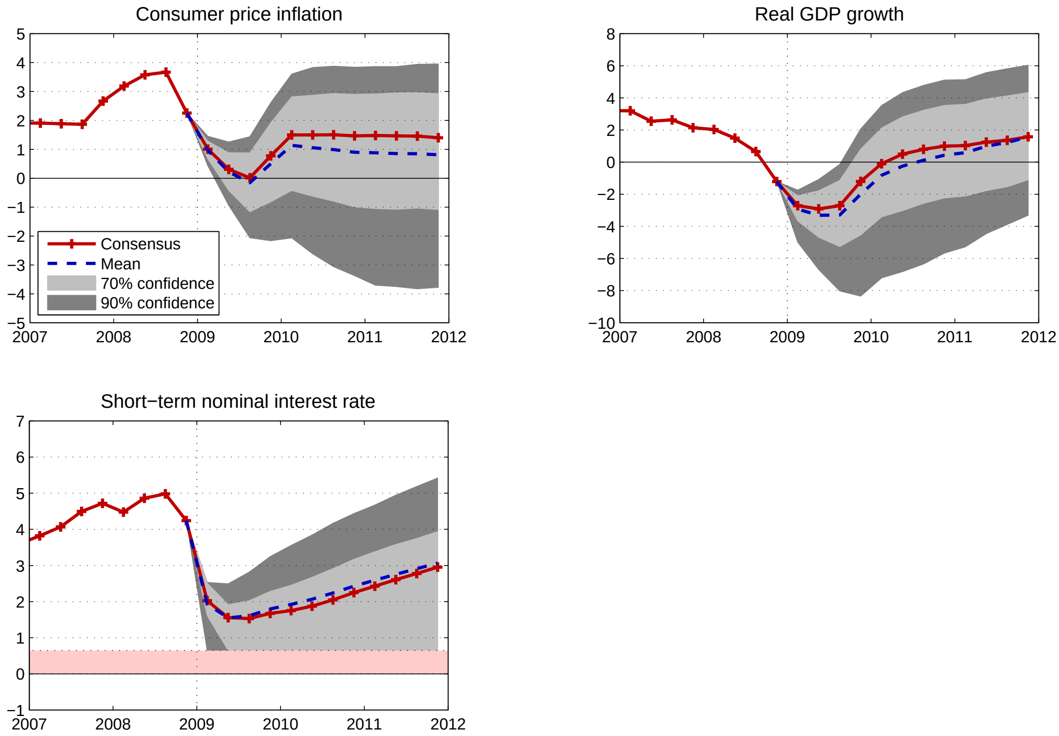
Note: See Table 5. The mean effects represent the deviations from the means of the distributions for the December '11 forecast vintage, expressed in percentage points.

Table A: Gauging risks to price stability and the lower bound incidence over a uniform 9-quarter horizon.

	Risks to price stability		Lower bound incidence
	Deflation	Excess inflation	
December '08	4.4	15.3	6.0
March '09	12.5	8.0	17.4
June '09	14.8	7.6	12.2
September '09	11.7	8.9	17.5
December '09	9.2	9.3	17.7
March '10	8.9	10.1	21.7
June '10	7.9	14.8	26.0
September '10	6.7	18.7	22.6
December '10	5.6	19.8	19.0
March '11	2.5	32.9	8.3
June '11	2.3	35.1	9.0
September '11	5.7	24.5	25.2
December '11	6.8	24.6	29.0
Steady state	1.1	28.3	0.2

Note: See Table 1. The steady-state values are calculated from the predictive distributions for annual inflation and the short-term nominal interest rate initialised at the model's steady state and evaluated over a 9-quarter horizon.

Figure 1: Predictive distributions for consumer price inflation, real GDP growth and the short-term nominal interest rate, March '09.



Note: The predictive distributions are derived from stochastic simulations of the NAWM and are centred on the structural shocks that the model has identified for the March '09 Consensus forecast vintage. Consumer price inflation and real GDP growth are expressed in annual terms. The short-term nominal interest rate in the NAWM corresponds to the annualised 3-month EURIBOR. The lower bound is imposed at an interest rate level of 65 basis points, reflecting the average spread between the EURIBOR and the EONIA over the horizon of the forecast vintage.

Figure 2: Loss functions for alternative inflation preferences.

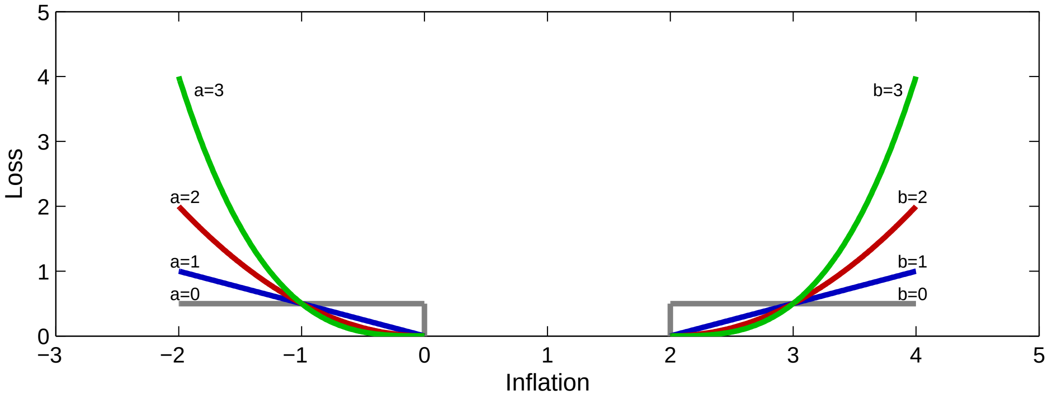
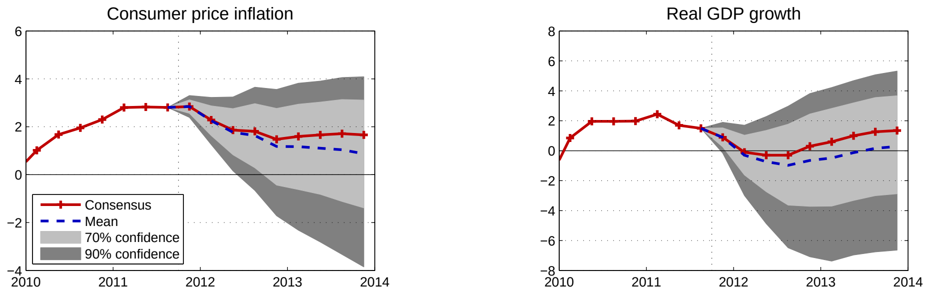
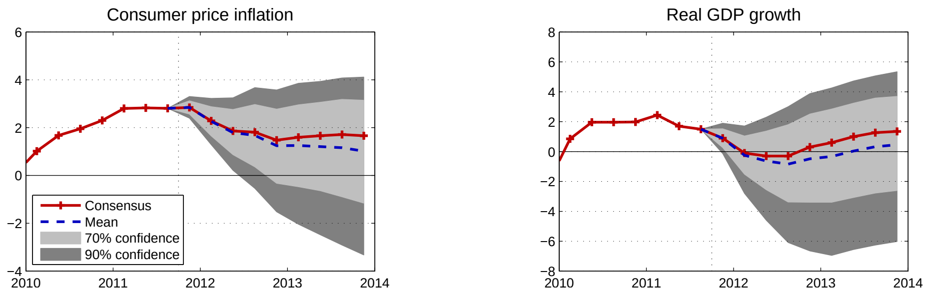


Figure 3: Predictive distributions for consumer price inflation and real GDP growth when keeping the nominal interest rate low for longer, December '11.

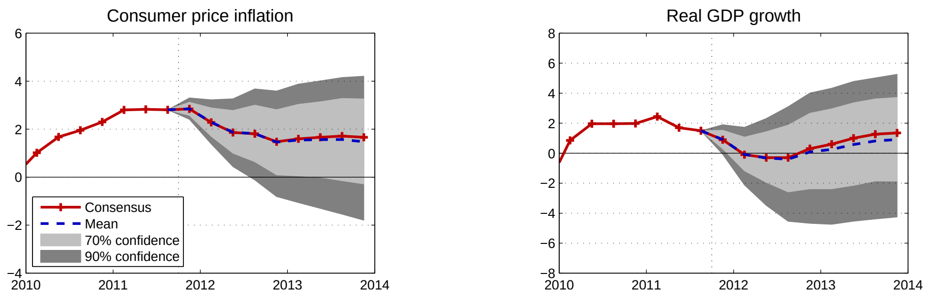
A. No conditional commitment



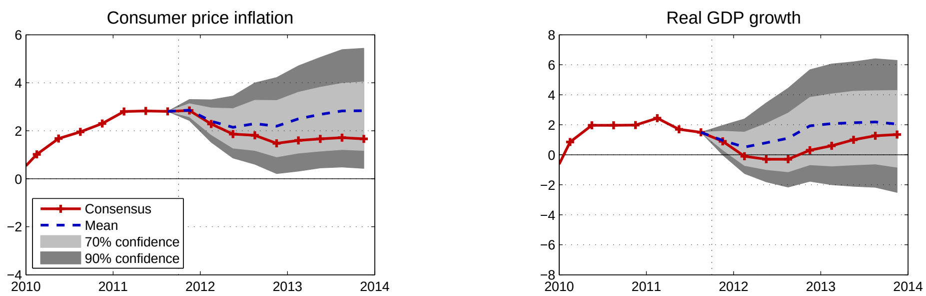
B. 1-quarter conditional commitment



C. 2-quarter conditional commitment

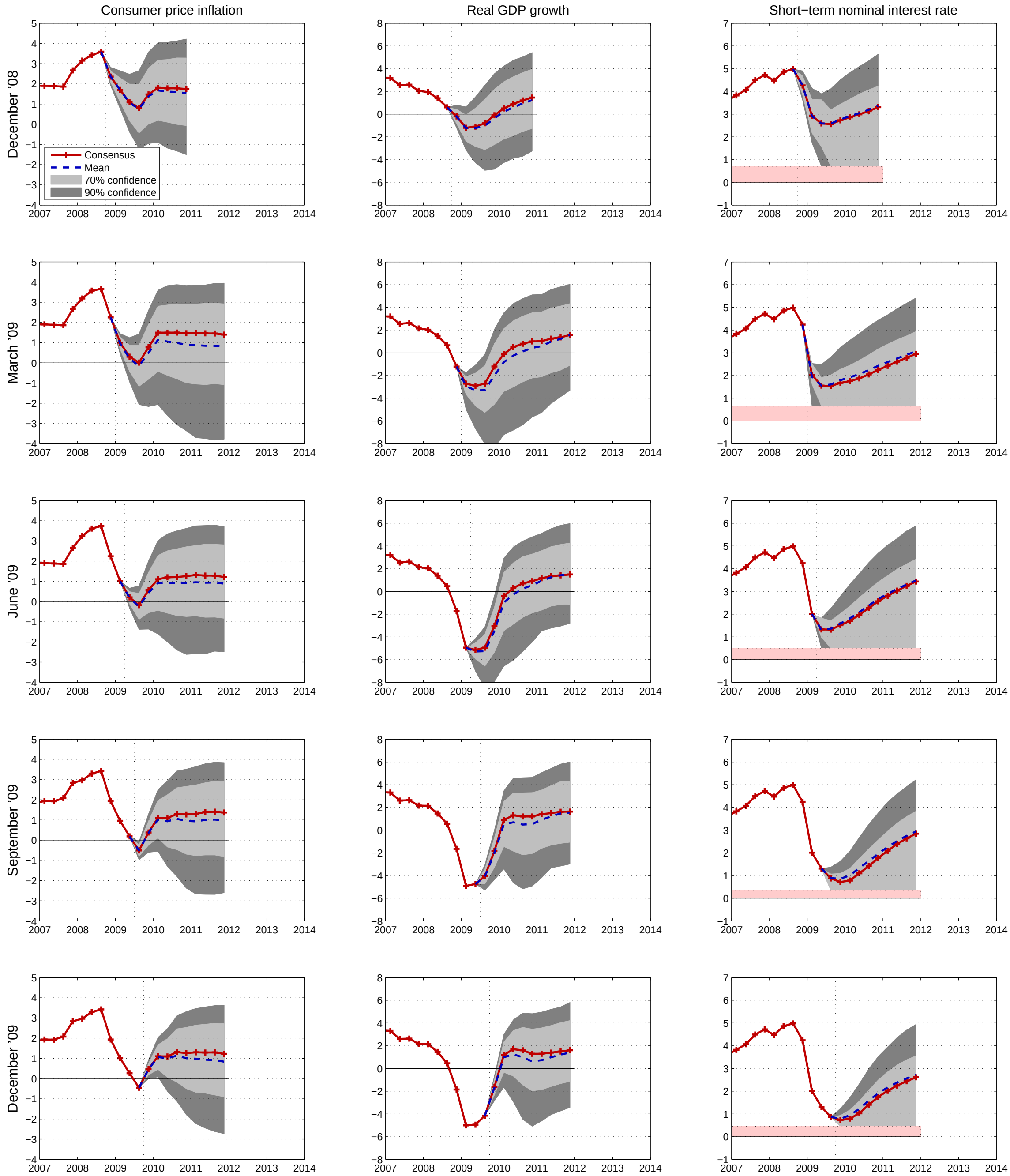


D. 3-quarter conditional commitment



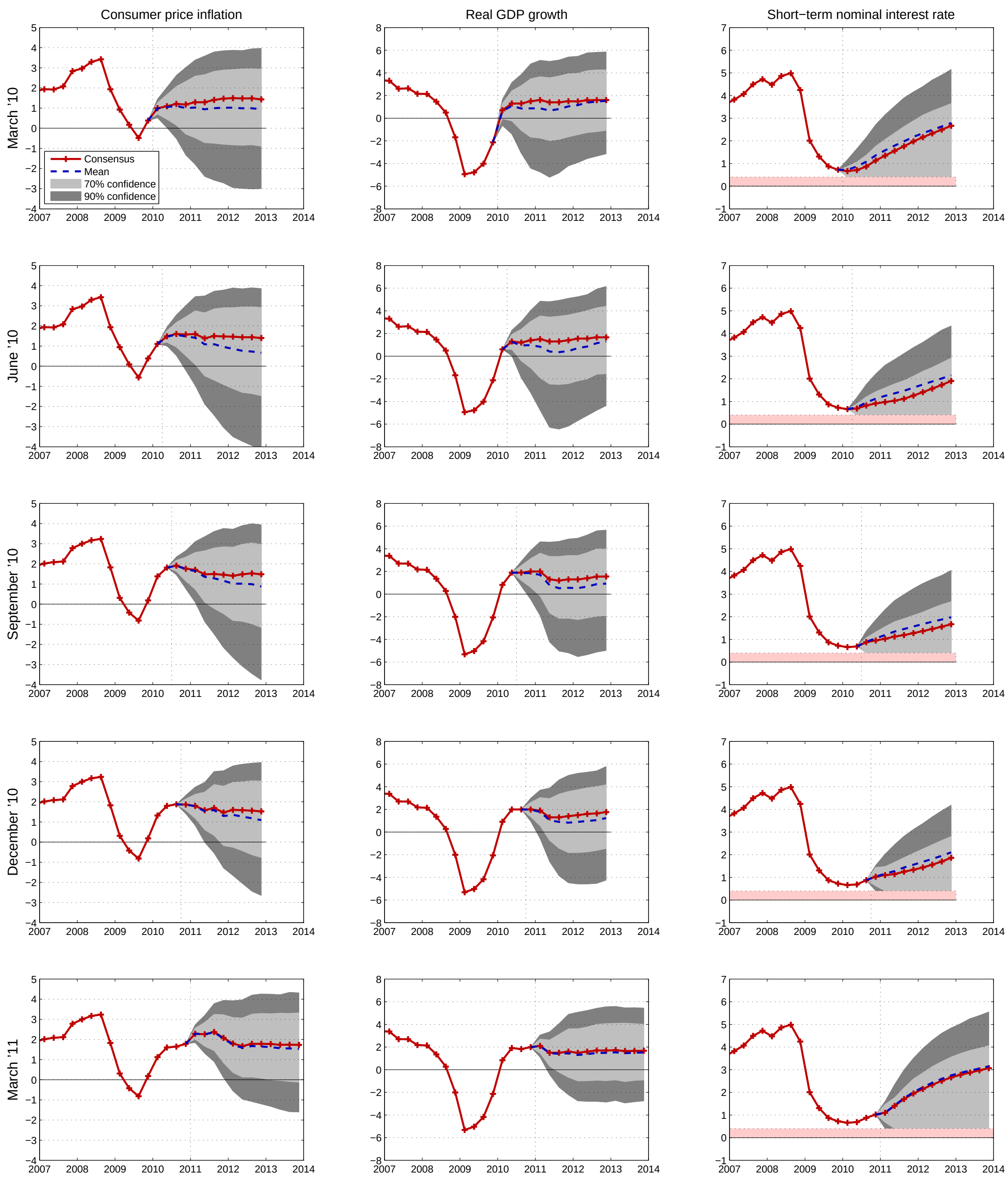
Note: See Figure 1 and Table 5.

Figure A: Predictive distributions for consumer price inflation, real GDP growth and the short-term nominal interest rate, December '08 to December '11.



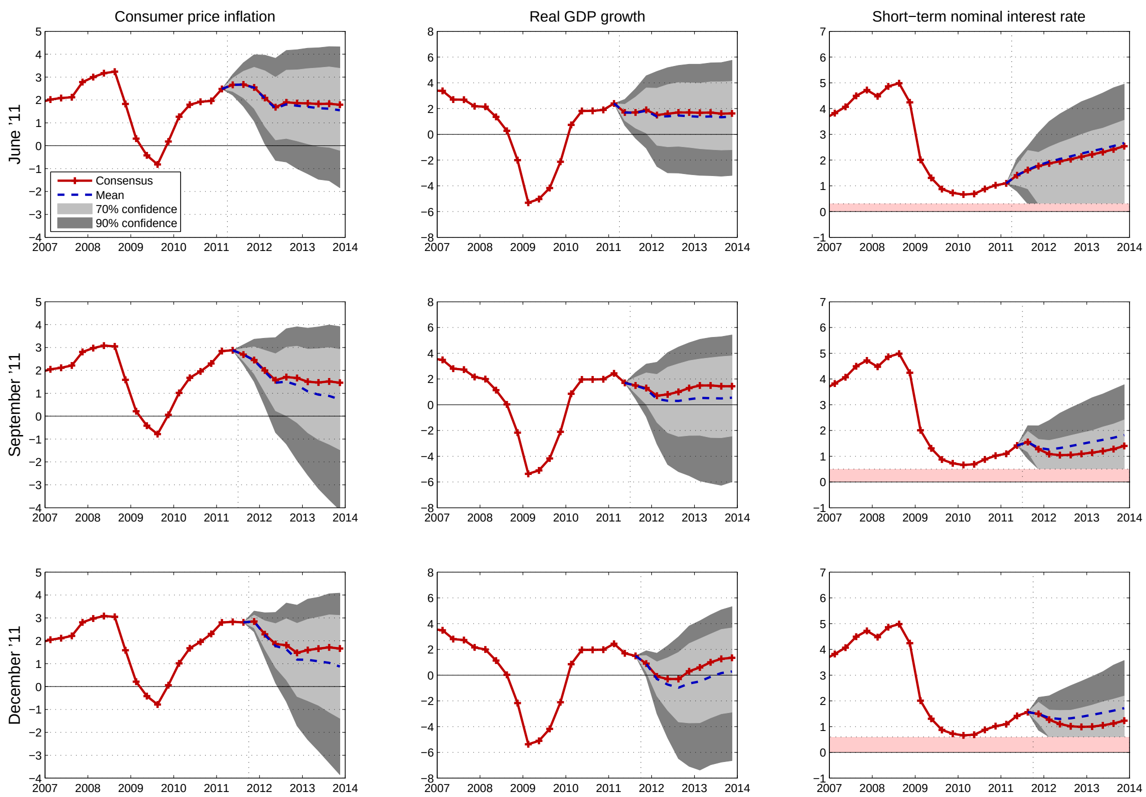
Note: The predictive distributions are derived from stochastic simulations of the NAWM and are centred on the structural shocks that the model has identified for the respective Consensus forecast vintage. Consumer price inflation and real GDP growth are expressed in annual terms. The short-term nominal interest rate corresponds to the annualised 3-month EURIBOR. The lower bound is imposed at interest rate levels between 30 and 70 basis points, reflecting the average spread between the EURIBOR and the EONIA over the horizon of the respective forecast vintage.

Figure A: Predictive distributions for consumer price inflation, real GDP growth and the short-term nominal interest rate, December '08 to December '11. (cont'd)



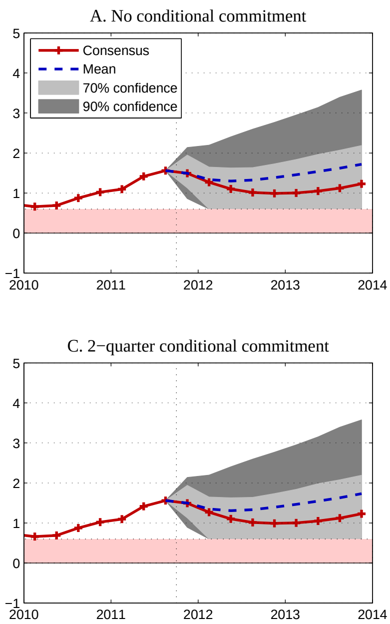
Note: See above.

Figure A: Predictive distributions for consumer price inflation, real GDP growth and the short-term nominal interest rate, December '08 to December '11. (cont'd)



Note: See above.

Figure B: Predictive distributions for the short-term nominal interest rate when keeping the interest rate low for longer, December '11.



Note: See Figure 3.