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Effects of state-dependent forward guidance, large-scale asset purchases and fiscal stimulus in a low-interest-rate environment

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Abstract

We study the incidence and severity of lower-bound episodes and the efficacy of three types of state-dependent policies—forward guidance about the future path of interest rates, large-scale asset purchases and spending-based fiscal stimulus—in ameliorating the adverse consequences stemming from the effective lower bound on nominal interest rates. In particular, we focus on the euro area economy and examine, using the ECB's New Area-Wide Model, the consequences of the lower bound both for the near-term economic outlook, characterised by persistently low nominal interest rates and inflation, and in a lasting low-real-interest-rate world. Our findings suggest that, if unaddressed, the lower bound can have very substantial costs in terms of worsened macroeconomic performance. Forward guidance, if fully credible, is most powerful and can largely undo the distortionary effects due to the lower bound. A combination of imperfectly credible forward guidance, asset purchases and fiscal stimulus is almost equally effective, in particular when asset purchases enhance the credibility of the forward guidance policy via a signalling effect.

JEL Classification System: E31, E32, E37, E52, E62

Keywords: Effective lower bound, monetary policy, forward guidance, asset purchases, fiscal policy, euro area

Non-technical summary

The Global Financial Crisis, the secular fall in the equilibrium real interest rate and the protracted period with nominal interest rates at their effective lower bound experienced in major advanced economies have led to a re-assessment of the incidence and severity of lower-bound episodes and of the effectiveness of existing monetary policy frameworks to safeguard macroeconomic stability. At the same time, central banks have gained considerable experience with the use of non-standard monetary policy tools such as forward guidance about the likely future path of interest rates and the conduct of large-scale asset purchases. These tools helped to soften the adverse consequences of the lower-bound constraint by supporting economic activity and were key for preserving price stability.

Against this background, this paper studies quantitatively the effects of forward guidance and large-scale asset purchases in a low-interest-rate environment in which the ability of monetary policy to stave off recessionary and deflationary shocks by adjusting its standard interest-rate instrument is impaired because of the effective lower bound. It adds to the literature by considering the euro area economy and by also taking into consideration expansionary fiscal policy as an additional stabilisation tool when the nominal interest rate has fallen to the lower bound. Moreover, the analysis in the paper takes into account the state-dependent nature of the three alternative policies, and their possible interaction, which is crucial for appropriately capturing their macroeconomic effects.

The quantitative analysis comprises two complementary exercises and employs, as a laboratory, the recent extension of the ECB's New Area-Wide Model with a financial sector. In the first exercise, we carry out stochastic simulations around a recent vintage of the Eurosystem staff projections. This projection vintage features an interest-rate baseline path which stays close to the perceived effective lower bound over the projection horizon and a baseline path for inflation which only gradually reverts to levels consistent with the ECB's price stability objective of keeping inflation below, but close to, 2%. The baseline combination of low nominal interest rates and low inflation translates into a very high likelihood that short-term nominal interest rates will fall to their effective lower bound during a possible future economic downturn. Accordingly, we assess the risks to the baseline outlook on the basis of model-based predictive distributions for inflation, real GDP growth and the short-term nominal interest rate computed from the stochastic simulations.

In the second exercise, we take a long-term perspective independent of current economic conditions and conduct stochastic simulations to study model-based steady-state distributions for inflation, the output gap and the short-term nominal interest rate. As both the size and the permanence of the fall in the equilibrium real interest rate are subject to a high degree of uncertainty, we compute these steady-state distributions under different assumptions about the level of the model's steady-state real interest rate, with a lower level of the real rate making it increasingly more likely that the effective lower bound on nominal interest rates will constrain monetary policy.

The findings of the two model-based exercises suggest that, if unaddressed, the lower bound can have very substantial costs in terms of worsened macroeconomic performance. In the current low-inflation and low-interest-rate environment, the effective lower bound amplifies the impact of adverse shocks on inflation and GDP growth, leading to elevated deflation and recession risks and downward biases in the respective predictive distributions. Similarly, in a world with a lastingly lower equilibrium real interest rate, the lower-bound constraint can significantly impair overall macroeconomic stabilisation performance, as reflected in inflated root mean-squared errors (RMSEs) of the steady-state distributions for inflation and the output gap. The adverse effects of the lower bound on these distributions are larger, the lower the equilibrium real interest rate.

Asset purchases and spending-based fiscal stimulus by themselves do redress part of the distortions due to the lower-bound constraint. If strong asset purchases are combined with fiscal stimulus, the RMSEs of the steady-state distributions for inflation and real GDP growth can be reduced by up to one half, even when taking into account that fiscal stimulus is eventually enacted with less ease and immediacy. If fully credible, forward guidance on interest rates is most powerful and can largely undo the distortionary effects due to the lower bound, even in a lasting low-interest-rate world with an equilibrium real interest rate of zero. Such strong forward guidance may not be realistic, but the combination of a weaker form of forward guidance, asset purchases and fiscal stimulus is almost equally effective, in particular when asset purchases enhance the credibility of the forward guidance policy via a signalling effect. The average amount of assets purchased is reasonable, as is the average size of the fiscal stimulus, but the ultimate amount of asset purchases needed can still be substantial in extreme circumstances.

The findings of the paper are of relevance for the review of monetary policy frameworks that some major central banks have recently embarked on. On the one hand, they suggest that it is of utmost importance that central banks maintain their approximate 2% inflation buffer in order not to compound the distortions associated with a lower equilibrium real interest rate. On the other hand, with effective non-standard monetary policies there may be no need to raise the prevailing inflation targets from around 2% to higher values, as suggested by a number of economists. More analysis is, however, needed to investigate the robustness of these findings using different modelling approaches.

1 Introduction

The Global Financial Crisis, the secular fall in the equilibrium real interest rate[1] and the protracted period with nominal interest rates at their effective lower bound experienced in major advanced economies have led to a re-assessment of the incidence and severity of lower-bound episodes and of the effectiveness of existing monetary policy frameworks to safeguard macroeconomic stability. At the same time, central banks have gained considerable experience with the use of non-standard monetary policy tools such as forward guidance about the likely future path of interest rates and the conduct of large-scale asset purchases. These tools helped to soften the adverse consequences of the lower-bound constraint by supporting economic activity and were key for preserving price stability.[2]

Against this background, our paper studies quantitatively the effects of forward guidance and large-scale asset purchases in a low-interest-rate environment in which the ability of monetary policy to stave off recessionary and deflationary shocks by adjusting its standard interest-rate instrument is impaired because of the effective lower bound. In so doing, the paper contributes to the literature on the conduct and efficacy of monetary policy at the effective lower bound, including the recent papers by Reifschneider (2016), Kiley and Roberts (2017), Kiley (2018) and Chung et al. (2019), which however all focus on the policies of the Federal Reserve and the US economy. Our paper adds to this literature[3] by considering the euro area economy and by also taking into consideration expansionary fiscal policy as an additional stabilisation tool when the nominal interest rate has fallen to the lower bound, as called for by Blanchard (2019), Eichenbaum (2019) and Rachel and Summers (2019) in the context of the recent debate on rethinking macroeconomic policy (cf. Blanchard and Summers, 2019). Moreover, the quantitative analysis in our paper takes into account the state-dependent nature of the three alternative policies, and their possible interaction, which

[1]For a documentation of the downward trend in the equilibrium real rate over the past decades and across countries, see, e.g., Laubach and Williams (2016), Hamilton et al. (2016), Holston et al. (2017), Brand et al. (2018) and Jordà and Taylor (2019). The uncertainty around the available estimates of the equilibrium rate and about whether it will remain at its current low levels in the future is however large.

[2]See Hartmann and Smets (2018) and ECB (2019) for an account of the experience with the implementation of the ECB's asset purchase programme and its interaction with other non-standard monetary policy measures, including the ECB's forward guidance on its key policy rates. For an assessment of the respective Federal Reserve policies, see Engen et al. (2015), Chung et al. (2019) and Sims and Wu (2019).

[3]Another recent literature studies the ability of alternative monetary policy frameworks to overcome the constraint on monetary policy due to the lower bound. For example, Bernanke (2017) and Bernanke et al. (2019), examine the benefits of temporary, or permanent, switches to a price-level targeting framework, whereas Mertens and Williams (2019) study average inflation targeting. Within the common inflation-targeting framework Andrade et al. (2018) analyse the relationship between the equilibrium real interest rate and the optimal inflation objective. By contrast, our analysis remains within the existing monetary policy framework of the ECB, and focuses instead on the efficacy of its non-standard policy instruments.

is crucial for appropriately capturing their macroeconomic effects.

Our quantitative study comprises two complementary model-based exercises. In the first exercise, we carry out stochastic simulations around a recent vintage of the Eurosystem staff projections. This projection vintage features an interest-rate baseline path which stays close to the perceived effective lower bound over the projection horizon and a baseline path for inflation which only gradually reverts to levels consistent with the ECB's price stability objective of keeping inflation below, but close to, 2% per annum. The baseline combination of low nominal interest rates and low inflation translates into a very high likelihood that short-term nominal interest rates will fall to their effective lower bound during a possible future economic downturn. Considering such a real-time setting seems more relevant from a policy perspective than a hypothetical adverse scenario resulting from a large contractionary shock, which is typically studied in the literature. As in Coenen and Warne (2014), we assess the risks to the baseline economic outlook on the basis of the model-based predictive distributions for inflation, real GDP growth and the short-term nominal interest rate computed from the stochastic simulations. Specifically, we characterise these distributions in terms of measures of deflation and recession risks and of the lower-bound incidence, and in terms of the mean effects on inflation and real GDP growth due to the lower-bound constraint. Within this setting, we then study the effectiveness of forward guidance about future interest rates and large-scale asset purchases to overcome the lower-bound constraint and impart the intended monetary accommodation in the event of an unforeseen economic downturn. In the same vein, we examine the efficacy of government spending-based fiscal stimulus in safeguarding the baseline outlook, as well as the extent to which it may allow to keep the amount of asset purchases more contained.

In the second exercise, we take a long-term perspective independent of current economic conditions and study model-based steady-state distributions for inflation, the output gap and the short-term nominal interest rate, like in Kiley (2018). As both the size and the permanence of the fall in the equilibrium real interest rate are subject to a high degree of uncertainty, we compute these steady-state distributions under different assumptions about the level of the model's steady-state real interest rate, with a lower level of the real rate making it increasingly more likely that the effective lower bound on nominal interest rates will constrain monetary policy. Using the model-based steady-state distributions, we first gauge the impact of a lower equilibrium real rate on the ability of monetary policy to stabilise inflation and activity when it can only resort to its standard interest-rate instrument subject to the lower-bound constraint. We then examine the extent to which forward guidance, asset purchases or spending-based fiscal stimulus can ameliorate the adverse effects stemming from the lower bound in a lasting low-real-interest-rate world.

To carry out the stochastic simulations, we employ the recent extension of the ECB's New Area-Wide Model (cf. Coenen et al., 2018), henceforth referred to as NAWM II. This model incorporates a rich financial sector with the threefold aim of (i) accounting for a genuine role of financial frictions in the propagation of economic shocks as well as macroeconomic policies and for the presence of shocks originating in the financial sector itself, (ii) capturing the prominent role of bank lending rates and the gradual interest-rate pass-through in the transmission of monetary policy in the euro area, and (iii) providing a structural framework useable for assessing the macroeconomic impact of the ECB's large-scale asset purchases conducted in recent years.[4]

In contrast to its original specification, the Taylor-type interest-rate rule in NAWM II is modified to track a shadow interest rate, which represents the notional short-term nominal interest rate which the central bank in the model would like to set given current economic conditions if it had not been constrained by the effective lower bound. The shadow rate in turn keeps track of the severity of unfolding economic downturns and ensuing shortfalls of inflation below the central bank's inflation objective, and makes the period for which the nominal interest rate is kept at the effective lower bound depend on the severity of these events. In other words, the interest-rate rule is modified to incorporate state-dependent forward guidance about the future path of interest rates once the effective lower bound is reached. In a similar vein, asset purchases and/or fiscal stimulus are triggered in a state-dependent manner whenever the short-term nominal interest rate falls to the lower bound following a sequence of adverse economic shocks.

Our two complementary approaches to conducting model-based stochastic simulations provide a rich laboratory for evaluating the efficacy of state-dependent forward guidance, state-dependent asset purchases and state-dependent fiscal stimulus in a low-interest-rate environment in which periods during which nominal rates are stuck at their effective lower bound are much more frequent. Our findings suggest that, if unaddressed, the lower bound can have very substantial costs in terms of worsened macroeconomic performance. In the current low-inflation and low-interest-rate environment, the effective lower bound amplifies the impact of adverse shocks on inflation and GDP growth, leading to elevated deflation and recession risks and downward biases in the respective predictive distributions. Similarly, in

[4]For a detailed description of the model, see Coenen et al. (2018). A short non-technical overview of its structure is provided in Appendix A.

a world with a lastingly lower equilibrium real interest rate, the lower-bound constraint can significantly impair overall macroeconomic stabilisation performance, as reflected in inflated root mean-squared errors (RMSEs) of the steady-state distributions for inflation and the output gap. The adverse effects of the lower bound on these distributions are larger, the lower the equilibrium real interest rate: As the equilibrium rate falls from 2% to zero, the lower-bound incidence rises from 6% to 16%, and the RMSEs for inflation and the output gap rise from 2.9% and 8.4% to 7.6% and 20.7%, respectively.

Asset purchases and fiscal stimulus by themselves do redress part of the distortions due to the lower-bound constraint. If strong asset purchases are combined with fiscal stimulus, the biases in the steady-state distributions for inflation and real GDP growth can be reduced by roughly half, even when taking into account that fiscal stimulus is eventually enacted with less ease and immediacy. As a result, and focusing on the extreme case with an equilibrium real rate of zero, the average of the RMSEs of the steady-state distributions for inflation and the output gap drops from 14.1% to 7.1%. This involves substantial asset purchases by the central bank resulting in asset holdings of, on average, 16% of (annual) GDP and a sizeable fiscal stimulus of, on average, 0.75% of GDP. At the same time, the lower-bound incidence is not very much affected. If strong, i.e. fully credible, forward guidance on interest rates is most powerful and can largely undo the distortionary effects due to the lower bound, even in a lasting low-interest-rate world with an equilibrium real rate of zero. Such strong forward guidance may not be realistic, but the combination of a weaker form of forward guidance, asset purchases and fiscal stimulus is almost equally effective, in particular when asset purchases enhance the credibility of the forward guidance policy, akin to a signalling effect. In accordance with its "low-for-longer" element, the number of times the short-term nominal interest rate stays at the lower bound does rise from roughly 16% to about 25.5% for an equilibrium real rate of zero, while the average duration of lower-bound episodes rises from 6 quarters to about 13 quarters. The average amount of assets purchased is reasonable, as is the average size of the fiscal stimulus, but the ultimate amount of asset purchases needed can still be substantial in extreme circumstances.

The remainder of the paper is organised as follows. Section 2 specifies the three types of state-dependent policies that we consider in our model-based study. Section 3 presents the findings of our analysis of the adverse consequences of the lower-bound constraint for the near-term outlook and the ability of the alternative state-dependent policies to mitigate them. Section 4 reports the results of the steady-state analysis of the distortionary impact of the lower bound on overall macroeconomic performance and the compensating effects of the state-dependent policies for alternative levels of the equilibrium real interest rate. Section 5 concludes. A brief overview of the model and technical details on the model solution and simulation methods are deferred to appendices.

2 State-dependent policies

In this section, we describe the specification and parameterisation of the three types of state-dependent policies that we consider in the paper: forward guidance about the future path of the short-term nominal interest rate, asset purchases and fiscal stimulus.

2.1 Forward guidance

In our analysis of the effects of state-dependent forward guidance about future short-term nominal interest rates, we focus on history-dependent interest-rate rules which lead to low-for-longer policy prescriptions. An early example of a rule falling in this category is the rule by Reifschneider and Williams (2000). According to this rule, current and future short-term nominal interest rates are set to make up the cumulated values of past shortfalls of the *shadow interest rate* below the effective lower bound on nominal rates. The shadow interest rate is defined as the notional interest rate which the central bank would like to set given current economic conditions if it had not been constrained by the effective lower bound. In models with forward-looking agents such as NAWM II, this rule proves to be extremely effective in overcoming the lower-bound constraint as it still succeeds to influence economic agents' expectations in situations when the current interest rate is stuck at the lower bound because of its history-dependent element.[5]

We consider a weaker version of this make-up rule which relates the short-term interest rate to the *lagged value* of the shadow-rate shortfall as opposed to its *cumulated past values*, like in Debortoli et al. (2018).[6] Concretely, we incorporate state-dependent forward guidance into the estimated log-linear interest-rate rule of NAWM II subject to the lower-bound

[5]The use of history-dependent rules differs from simulating a forward-looking model under a transient, but exogenous, interest-rate peg to mimic a low-for-longer policy. The latter gives rise to the forward guidance puzzle—that is, an extreme sensitivity of simulation outcomes to keeping the short-term nominal interest rate at the lower bound for longer (see Del Negro et al., 2012, and Carlstrom et al., 2012). Under an interest-rate peg, such behaviour is also observed for NAWM II.

[6]We do not consider alternative history-dependent rules such as price-level targeting rules (Vestin, 2006, Bernanke, 2017, Bernanke et al., 2019), or average-inflation targeting rules (Nessén and Vestin, 2005, Mertens and Williams, 2019). These rules imply a change in the monetary policy framework, which we do not contemplate in this paper. Similarly, we do not consider threshold-based rules (Coenen and Warne, 2014, Boneva et al., 2018, Chung et al., 2019), which rely on an alternative mechanism to induce low-for-longer policy prescriptions.

constraint as follows:

$$r_t \quad = \quad \max[\,\tilde{r}_t,\, -100\cdot\log(\bar{R}) + \mathit{ELB}\,] \tag{1}$$

with

$$\begin{aligned}\tilde{r}_t \quad = \quad & \phi_R\,(\iota\, r_{t-1} + (1-\iota)\,\tilde{r}_{t-1}) + (1-\phi_R)\,\left(r^r_{t|t} + \phi_{\Pi_C}\,\pi_{C,t} + \phi_Y\,y_t\right) \\ & + \phi_{\Delta\Pi_C}\,(\pi_{C,t} - \pi_{C,t-1}) + \phi_{\Delta Y}\,(y_t - y_{t-1}) + \eta^R_t.\end{aligned} \tag{2}$$

Here, $r_t = 100\cdot\log(R_t/\bar{R})$ is the short-term nominal interest rate which the central bank can implement subject to the effective lower bound, *ELB*, while $\tilde{r}_t$ represents the notional shadow interest rate. The long-run, or steady-state, (gross) nominal interest rate $\bar{R}$ is determined as the product of the steady-state equilibrium (gross) real interest rate $\bar{R}^r$ and the steady-state (gross) inflation rate $\bar{\Pi}$, which is pinned down by the central bank's long-run inflation objective.

In the model's interest-rate rule, $\pi_{C,t}$ denotes the logarithmic deviation of (gross) consumer price inflation $\Pi_{C,t}$ from the steady-state inflation rate. Similarly, y_t is the logarithmic deviation of aggregate output Y_t from the trend output level, with trend output growth following a shock process which is the composite of a persistent and a transitory component. In an attempt to empirically capture part of the decline in the equilibrium real interest rate due to the slowing of trend growth, $r^r_{t|t}$ represents the central bank's estimate of the medium-term fluctuations in the logarithmic deviation of the equilibrium real interest rate from its long-run value due to the persistent component of trend output growth. Finally, η^R_t is a transitory shock capturing temporary deviations of the short-term nominal interest rate from the systematic prescriptions of the interest-rate rule.

Importantly, in computing the value of the shadow interest rate, the parameter $\iota \in \{0,1\}$ determines whether the shadow rate depends on the lagged realised interest rate ($\iota=1$), or on the lagged shadow interest rate ($\iota = 0$). In the latter case, the shadow rate keeps track of the severity of a recession or a shortfall of inflation below the central bank's inflation objective and makes the period for which the interest rate is kept at the effective lower bound depend on the severity of the respective event. In other words, the interest-rate rule embeds *state-dependent forward guidance* about the future interest-rate path.

The case with $\iota = 0$ can be interpreted as the case of fully credible, or *strong*, interest-rate forward guidance, with $\tilde{r}_t = \tilde{r}_t(\tilde{r}_{t-1})$. As the assumption of full credibility is arguably unrealistic we consider two modifications. First, imperfectly credible, or *weak*, forward guidance can be thought of as a case in which private-sector agents base their expectations of future interest rates on a linear combination of two distinct interest-rate rules which feature either the shadow rate depending on the lagged realised rate, $\tilde{r}_t(r_{t-1})$, or the shadow rate depending on its own lag, $\tilde{r}_t(\tilde{r}_{t-1})$. This is tantamount to assuming that a certain share of private-sector agents believe in the central bank's rate forward guidance, whereas the remaining share does not. And second, as a simple means to account for the signalling channel of asset purchases, the case of *enhanced* forward guidance assumes that asset purchases carried out by the central bank lead to an increase in the share of agents that believe in its guidance compared to the case of weak forward guidance.[7]

In our implementation of the two modifications concerning the way agents form their expectations of future interest rates, the current interest rate continues to be determined according to the interest-rate rule (2) with $\iota = 0$. That is, the central bank sets the interest rate period-by-period in line with its shadow-rate-based forward guidance policy. Agents that do not believe in this policy and observe the realisation of the current-period interest rate could in principle infer the true policy intentions of the central bank for the future, yet such an element of learning is not taken into account in our implementation.

2.2 Asset purchases and fiscal stimulus

In our analysis we link the specification of state-dependent asset purchases and fiscal stimulus to the shortfall of the shadow interest rate below the effective lower bound. For asset purchases, a_t, we consider the following rule:

$$a_t \;=\; \rho_{a,1}\, a_{t-1} + \rho_{a,2}\, a_{t-2} + \alpha_a \, \max[\, r_t^{gap} - c_a,\, 0\,], \tag{3}$$

where $r_t^{gap} = r_t - \tilde{r}_t(\kappa\, r_{t-1} + (1-\kappa)\, \tilde{r}_{t-1})$ represents a measure of the current interest-rate shortfall, α_a determines the sensitivity of asset purchases with respect to the interest-rate shortfall and, hence, their *strength*, and c_a is a threshold parameter determining the *immediacy* of the purchases. The assumed AR(2) process for the dynamic propagation of the initial asset purchases, with appropriately chosen parameters $\rho_{a,1}$ and $\rho_{a,2}$, allows for a gradual build-up of overall asset holdings broadly consistent with the pattern of actual asset purchases carried out by central banks, and a gradual reduction thereafter as the purchased assets mature. Like for the counterfactual analysis of the ECB's initial asset purchase programme in Coenen et al. (2018), the state-dependent asset purchases in this paper

[7] For a rigorous treatment, see Bhattarai et al. (2015) who argue that asset purchase policies exert their influence through signalling the central bank's commitment to maintain low interest rates in the future and provide an explicit signalling theory of asset purchases.

comprise purchases of long-term government bonds and long-term private-sector loans; see Appendix A for details on the financial sector in NAWM II.

The parameter $\kappa \in \{0,1\}$ determines whether the shadow interest rate used in the computation of the interest-rate shortfall depends on the lagged realised rate ($\kappa = 1$, with $\tilde{r}_t = \tilde{r}_t(r_{t-1})$), or on the lagged shadow rate ($\kappa = 0$, with $\tilde{r}_t = \tilde{r}_t(\tilde{r}_{t-1})$). The value of κ does not need to coincide with the value of ι. In particular, in the case that the actual shadow rate depends on the lagged shadow rate ($\iota = 0$)—that is, if the interest-rate rule embeds rate forward guidance—the interest-rate gap may still be more conveniently computed using the alternative shadow-rate measure based on the lagged realised rate ($\iota = 1$). This facilitates the calibration of the strength of the state-dependent asset purchases for the alternative specifications of the interest-rate rule with and without forward guidance.

We specify a similar state-dependent rule for imparting additional fiscal stimulus, f_t, in a situation where the short-term interest rate is constrained by the effective lower bound:[8]

$$f_t \;=\; \rho_f\, f_{t-1} + \alpha_f\, \max[\, r_t^{gap} - c_f,\, 0\,], \tag{4}$$

with α_f determining the strength of the fiscal stimulus, c_f representing a threshold, and the dynamics being restricted to an AR(1) process with parameter ρ_f. Throughout the analysis, the fiscal stimulus corresponds to an increase in government consumption spending; see Appendix A for details on the government sector in NAWM II.

2.3 Parametrisation

First, regarding the formulation of the lower-bound constraint (1), we will consider alternative values for the steady-state short-term nominal interest rate $\bar{r}^{(4)} = \bar{r}^{r,(4)} + \bar{\pi}^{(4)} = 400 \cdot \big(\log(\bar{R}) + \log(\bar{\Pi})\big)$, expressed as annualised percentages for the sake of convenience. Specifically, we let the steady-state short-term real interest rate $\bar{r}^{r,(4)}$ take on the alternative values of 2%, 1% and 0%, roughly spanning the range of values circumscribing the documented secular decline in the long-run equilibrium real rate over the past two decades. At the same time, we keep the model's steady-state inflation rate constant at 1.9%, consistent with the ECB's price stability objective. The level of the effective lower bound, *ELB*, will be chosen depending on the nature of the two complementary simulation exercises presented in this paper and therefore be discussed below.

[8] Our fiscal-stimulus rule is very much in the spirit of the proposal by Eichenbaum (2019) to adopt a system of asymmetric, automatic stabilisers when certain macro indictors hit pre-specified targets indicating that the effective lower-bound constraint on interest rates is binding.

Second, the parameters of the interest-rate rule (2) are set equal to the parameter estimates reported in Coenen et al. (2018). In formulating assumptions about the differing degrees of effectiveness of interest-rate forward guidance, we postulate that weak forward guidance results in a substantial reduction in its ability to implement a low-for-longer policy and to undo the distortions due to the lower bound compared to the polar case of strong forward guidance. That is, we assume that there is a sufficiently large share of private-sector agents in the model that do not believe in the central bank's forward guidance policy. Enhanced forward guidance corresponds to the assumption that, in reaction to asset purchases carried out by the central bank, a larger share of agents start to trust the forward guidance policy. According to this narrative, we calibrate the share of agents placing trust in the forward guidance policy to rise from 25% for the case of weak forward guidance to 50% for the case of enhanced forward guidance.

Third, in the absence of empirical evidence, we consider alternative calibrations of the state-dependent asset-purchase rule (3). In particular, we explore the effects of differing degrees of sensitivity of asset purchases to the interest-rate shortfall, with $\alpha_a = 0.5$ ("moderate") or $\alpha_a = 1$ ("strong"). As a default, we allow asset purchases to be carried out immediately once the short-term nominal interest rate falls to the effective lower bound, with $c_a = 0$. Yet since asset purchases may not be likely to be initiated if the economy is expected to stay at the lower bound for only a short period of time, with a small emerging interest-rate shortfall, we also consider a threshold value of 1/4 that must be exceeded before asset purchases are allowed to take hold. Concerning the parameters of the autoregressive component of the asset-purchase rule we consider a pair of values equal to $\rho_{a,1} = 1.5$ and $\rho_{a,2} =$ -0.54 (with roots equal to 0.9 and 0.6 for the associated lag polynomial). These values result in a peak effect for the overall holdings of assets that occurs after four quarters.

And finally, regarding the state-dependent fiscal-stimulus rule (4), we assume a sensitivity parameter of $\alpha_f = 5$, a threshold parameter with default value equal to $c_f = 1/4$ reflecting the fact that fiscal stimulus is eventually enacted with less ease and immediacy than monetary policy stimulus, and an autoregressive parameter of $\rho_f = 0.9$, which results in a persistent but monotonically decreasing stimulus pattern.

3 Consequences of the lower bound for the economic outlook

Future unforeseen events give rise to uncertainty and pose risks to the economic outlook which, if they materialise and threaten the outlook, will necessitate adjustments of the monetary policy stance. To gauge such risks in the *current* low-inflation and low-interest-rate environment, we employ NAWM II to construct *predictive distributions* for a number of key macroeconomic variables that feature, amongst others, prominently in the deliberations of monetary policy-makers. As we shall demonstrate below, unless addressed by other policies, the existence of an effective lower bound for nominal interest rates has a material impact on these distributions.

3.1 Model-based predictive distributions

To the extent that policy-makers do not base their deliberations narrowly on predictions of any single model, we start from a central prediction that incorporates a wide range of data and takes into account different models and perspectives, namely the baseline projection of the December 2018 Broad Macroeconomic Projection Exercise (BMPE) conducted by Eurosystem staff. We then carry out stochastic simulations with NAWM II to obtain predictive distributions around this baseline. In the simulations, we allow the short-term nominal interest rate to react to new shocks that may occur over the projection horizon according to the model's estimated interest-rate rule, while recognising the lower-bound constraint.[9] That is, we rely on a model-based characterisation of macroeconomic uncertainty, including the consequences of the lower bound, but account for the vastly broader information set used in actual policy-making.

3.1.1 Visual inspection of the distributions

Figure 1 displays the December 2018 BMPE baseline paths as well as the means and the 70% and 90% confidence bands of the NAWM II-based predictive distributions for annual real GDP growth, annual consumer price inflation (measured in terms of the private consumption deflator) and the annualised short-term nominal interest rate (corresponding to the 3-month EURIBOR). As can be seen in Panel A of the figure, when the effective lower bound for nominal interest rates is recognised, a larger part of the predictive distributions for real GDP growth and consumer price inflation lies below the respective baseline. Accordingly, these distributions are skewed to the downside, with their means falling noticeably below the baseline paths over the outer years of the projection horizon. The reason for the asymmetry of the predictive distributions is that, with short-term nominal interest rates

[9]Technical details on the stochastic simulations that we carry out around the December 2018 BMPE projection baseline and on the solution method that we use to solve NAWM II subject to the lower-bound constraint are provided in Appendix B.

in the baseline being very close to the perceived effective lower bound over the projection horizon,[10] the reaction of monetary policy to new recessionary and deflationary shocks via standard interest-rate adjustments is increasingly constrained. As a consequence, the lower-bound constraint implies a strong piling-up of the predictive distribution for the short-term nominal interest rate at the effective lower bound, with the short-term rate being markedly higher on average than in the baseline. By contrast, if the lower bound were not to be present, as assumed in Panel B of the figure, the predictive distributions for real GDP growth, consumer price inflation and the short-term nominal interest rate would all be symmetric, and their means would be equal to the baseline values.

Figure 2 depicts variants of the model-based predictive distributions for real GDP growth and consumer price inflation when alternative state-dependent policies can de deployed once the short-term nominal interest rate has fallen to the effective lower bound. These variants allow to visually inspect the relative efficacy of the state-dependent policies in terms of reducing the skew of the distributions due to the lower bound. The different panels of the figure consider, as examples, strong asset purchases (Panel A), spending-based fiscal stimulus (Panel B), the combination of strong asset purchases and fiscal stimulus (Panel C), strong and weak forward guidance (Panels D and E, respectively) and enhanced forward guidance brought about through the conduct of strong asset purchases by the central bank (Panel F); see Section 2 for the specification and parametrisation of the different policies. All these policies succeed in reducing the skew of the predictive distributions, albeit to varying degrees. Amongst the different policies, forward guidance is most effective, in particular if it is strong. In this case, the distributions are virtually indistinguishable from those in the unrestricted case, with their means basically coinciding.

3.1.2 Effects of an adverse demand shock

As is evident from the skew of the model-based predictive distributions, the effective lower bound can become a strong amplifier of shocks to the economic outlook. To highlight the underlying mechanism, the panels in Figures 1 and 2 also show the effects of an additional adverse demand shock that results in a fall of quarterly real GDP growth to roughly zero at the start of the December 2018 BMPE horizon. With the short-term nominal interest rate being persistently stuck at the effective lower bound (as shown in Panel A of Figure 1),

[10] The lower-bound constraint is imposed at an interest-rate level of -31.5 basis points, equal to the value of the EURIBOR at the start of the December 2018 BMPE horizon; that is, in 2018Q4. At the same time, we maintain the value of 3.9% for the model's steady-state short-term nominal interest rate, which is composed of the steady-state inflation rate of 1.9% (corresponding to the central bank's inflation objective) and the steady-state short-term real interest rate of 2% used in the estimation of the model.

the ensuing fall in inflation leads to a rise of the (ex ante) real interest rate. As a result, aggregate demand is dampened further, over and above the initial effect of the adverse demand shock, and real GDP grows more slowly than in a situation where the nominal interest rate can be lowered to partly offset the recessionary and deflationary effects of the demand shock (see Panel B in Figure 1). The heightened amount of economic slack implied by the lower-bound constraint lowers price pressures and, hence, inflation further, giving rise to an adverse feedback-loop operating in particular through the real-interest-rate channel. Other channels in the model include a tightening of financing conditions through an endogenous rise in interest-rate spreads and a real appreciation of the euro.

The different panels in Figure 2 indicate that the alternative state-dependent policies can all mitigate the adverse consequences of the additional demand shock in the presence of the lower bound, albeit to a different extent.[11] In order to help understand the working of the alternative policies and to more clearly discern the differences in their mitigating effects, Figure 3 zooms in on the outcomes for an enlarged number of variables, including the output gap (instead of real GDP growth), as well as the size of the asset purchases and of the fiscal stimulus triggered by the demand shock. For the sake of expositional clarity, the outcomes are shown as percentage-point deviations from the December 2018 BMPE baseline paths, except for the outcomes for the short-term nominal interest rate which are displayed in levels. The two polar cases when the effective lower bound is recognised and when the lower bound is not present (solid red lines and dashed red lines, respectively) provide benchmarks for assessing the relative effectiveness of the alternative state-dependent policies. Both strong asset purchases (solid blue lines) and fiscal stimulus (dashed blue lines) succeed in dampening the amplification of the adverse demand shock, with the impact of the spending-based fiscal stimulus being noticeably stronger to the extent that it directly influences aggregate demand.[12] At the same time, asset purchases and fiscal stimulus lead to an earlier lift-off of the short-term interest rate from the effective lower bound because of their

[11] This outcome rests on the assumption that the state-dependent asset-purchase and fiscal-stimulus policies are implemented without the threshold condition, as the interest-rate shortfall in response to the adverse aggregate demand shock is too small to exceed the threshold value of one-fourth.

[12] As a complementary means of demonstrating the effectiveness of asset-purchase and fiscal-stimulus policies in the presence of the lower-bound constraint, Appendix Figures A.1 and A.2 depict the effects of autonomous increases in the central bank's asset holdings and in government spending for the cases with endogenous interest-rate reaction and with interest rates being pegged for 4 quarters. To attenuate the occurrence of the forward guidance puzzle under the interest-rate peg (see the discussion in footnote 5), we assume that only a certain share of households and firms believes in the central bank's policy of keeping the short-term interest rate unchanged. The remaining share observes the interest rate set in the current period but builds expectations on the assumption that in future periods the central bank follows the model's interest-rate rule. See Montes-Galdón (2018) for details on the employed methodology.

positive effects on economic activity and inflation. If the two policies are deployed jointly (dotted blue lines), the dampening effect is strengthened, with the provision of fiscal stimulus lessening the need to resort to asset purchases. Strong interest-rate forward guidance (solid green lines) results in outcomes that are close to those for the unconstrained benchmark case. If weak (dashed green lines), the effectiveness of forward guidance is much reduced, with outcomes closer to those obtained using asset purchases or fiscal stimulus alone. However, if the effectiveness of forward guidance is enhanced because of its combination with asset purchases (dotted green lines), the outcomes are again much more favourable. As intended, strong forward guidance implies a low-for-longer policy prescription, with interest-rate lift-off from the effective lower bound occurring a few quarters later than in the constrained benchmark case. This prescription is not preserved when forward guidance is weak, with interest-rate lift-off a little earlier than in the constrained benchmark case, and it is only partly restored for enhanced forward guidance.

3.2 Gauging the effectiveness of state-dependent policies

The above visual inspection of the model-based predictive distributions around the December 2018 BMPE baseline and the illustrative analysis of the effects of an additional adverse demand shock provide a qualitative indication of the impairments of the economy due to the lower-bound constraint and of the efficacy of different state-dependent policies in overcoming these impairments. Below we use two alternative metrics to gauge the lower bound-related impairments and the efficacy of the state-dependent policies quantitatively. Moreover, we consider a more varied set of policies with the aim of exploring the sensitivity of their effectiveness to changes in their parameterisation.

3.2.1 Deflation and recession risks, and lower-bound incidence

We first assess the importance of downside risks to the December 2018 BMPE baseline and the efficacy of the different state-dependent policies in mitigating their amplification through the effective lower bound. We do this on the basis of alternative "risk measures", as in Coenen and Warne (2014). In particular, we associate downside risks to the baseline outlook with the emergence of *deflation*, which can be defined as the event that annual inflation falls below zero for at least four consecutive quarters, and with the slide of the economy into *recession*, which is defined as the event that quarterly real GDP growth is negative for at least two consecutive quarters. Our definition of deflation risk is motivated by the widely-held view that negative inflation rates ought to become a concern for policy-makers only in cases where they are persistent and translate in a sustained fall in the aggregate price level.[13] In measuring deflation risk, we also consider the *severity* of the deflation event, which is calculated as the mean value of inflation conditional on the economy being in a deflation state. This measure is of interest because the severity of the deflation event, together with its probability, determines the *expected loss* associated with the mergence of deflation which policy-makers obviously want to keep strictly contained. Finally, we also consider a measure of conditional deflation risk, which concerns deflation events conditional on being in a recession state. This measure is more likely to capture a genuine deflation event resulting from a severe economic downturn, as opposed to a disinflation event caused by a sequence of favourable supply-side shocks. The alternative risk measures are complemented by a measure of the *lower-bound incidence* which corresponds to the frequency of the event that the short-term nominal interest rate is constrained by the effective lower bound for at least one quarter.

Our findings regarding the importance of downside risks to the economic outlook and the relative efficacy of non-standard-policies in mitigating their amplification through the lower bound are summarised in Table 1. As benchmarks for our assessment, we use the values of the risk measures obtained for the two polar cases when the lower bound is recognised, whilst not allowing for additional state-dependent policies, and when the lower bound is disregarded; see the two items in the bottom panel of the table. In the constrained benchmark case, the short-term nominal interest rate is found to be stuck at the lower bound with an incidence of 38.2% (computed as an average across all quarters of the BMPE projection horizon). Evidently, this heightened incidence is in large part caused by the fact that the short-term interest rate in the baseline is expected to stay close to the lower bound. It comes along with elevated downside risks to the outlook, with a deflation probability of 10.8% and a conditional inflation mean of -2.2%. The recession probability is found to equal 22.5%, giving rise to a conditional deflation probability of 12%. If the lower-bound constraint were non-existent, the values of these risk measures would be lower by more than one third. In particular, the conditional deflation risk would be much more benign, with a value equal to 2%, confirming that the consequences of the lower-bound constraint are particularly severe in the event of recessionary shocks.

Panel A in Table 1 reports the impact of state-dependent asset purchases and state-

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

dependent fiscal stimulus on the risk measures and the lower-bound incidence in the absence of state-dependent forward guidance, considering different parameterisations of the associated rules. Asset purchases carried out alone are found to lower deflation and recession risks the more, the stronger the purchases, although the reduction of the deflation and recession risk measures remains modest and barely exceeds 0.4 and 0.7 percentage points even if the asset purchases are strong. In relative terms, the mitigating effect on the severity of the deflation risk is somewhat stronger, suggesting that asset purchases prove particularly effective in case the economic downturn is severe. At the same time, asset purchases result in a small decline of the lower-bound incidence as they tend to bring forward the lift-off of the interest rate from the effective lower bound. This decline is moderately rising in absolute value with the strength of the purchases. In case the conduct of asset purchases is subject to a threshold (equal to a one percentage-point shortfall of the annualised short-term nominal interest rate below the effective lower bound), the risk-reduction effect is even more limited. This suggests that the timely start of asset purchases in an economic downturn with interest rates at their lower bound is important to reap their full effect. Spending-based fiscal stimulus is found to result in stronger risk-reduction effects, at least if the fiscal-stimulus rule is not subject to a threshold condition. If strong asset purchases and fiscal stimulus are deployed jointly, the risk reduction-effects are enhanced, especially when both policies are implemented without thresholds.

Panel A in Table 2 provides information on the size of the asset purchases (measured in terms of the central bank's asset holdings as a percentage of GDP) and of the spending-based fiscal stimulus (measured as a percentage of GDP). The reported values correspond to the means and the 95% percentiles of their predictive distributions and are calculated for each individual calendar year covered by the BMPE horizon.[14] The size of both asset purchases and fiscal spending is rising over the projection horizon, as the lower-bound constraint is increasingly often binding and the interest-rate shortfall widens. Obviously, asset purchases are more sizeable if the strength of their response to the interest-rate shortfall is higher, and smaller if a threshold condition applies. Nevertheless, even if strong and not subject to a threshold, the central bank's accumulation of assets by the final year of the projection horizon remains contained, with a mean of below 8% of GDP. Similarly, the fiscal stimulus remains below 0.5% of GDP. However, in extreme circumstances, as measured by the 95% percentiles of the distributions, both asset accumulation and fiscal spending could be very sizeable, amounting up to 25% and 1.7% of GDP.

[14]The results for the year 2018 are not shown as they are quantitatively negligible.

Turning to the case of strong interest-rate forward guidance in Panel B of Table 1, we see that in this case the risk measures are substantially reduced and only moderately higher than in the unconstrained benchmark case. This result is consistent with the qualitative findings regarding the shape of the predictive distributions under strong forward guidance, as discussed above. It is noteworthy that the implied lower-bounded incidence of roughly 45.5% is markedly higher, in line with the intended low-for-longer prescription for the interest rate. If strong forward guidance is complemented with asset purchases, the additional reduction in the risk measures is modest, reflecting the more limited amount of asset purchases carried out (see Panel B in Table 2). This in turn reflects the emergence of a smaller interest-rate shortfall, as the strong forward guidance policy in itself is very effective in overcoming the lower-bound constraint. As shown in Panel C of Table 1, if interest-rate forward guidance is weak, the risk measures are reduced considerably less compared to the case of strong guidance. The risk-reduction effect of additional asset purchases is somewhat larger because of the smaller reduction in the interest-rate shortfall, leading to more sizeable asset purchases (see Panel C in Table 2). Finally, Panel D in Table 2 reports the results for the case of enhanced interest-rate forward guidance brought about through the conduct of asset purchases by the central bank. As already illustrated above, the effectiveness of such enhanced forward guidance is largely restored, resulting in a marked reduction of the risk measures compared to the case of weak forward guidance. If fiscal stimulus is provided additionally, the values of the risk measures are lowered further and can get even close to those in the unrestricted benchmark case.

3.2.2 Mean effects on inflation and output growth

Concerning the second metric used in our assessment of the efficacy of the different state-dependent policies in a low-inflation and low-interest-rate environment, Table 3 quantifies the effects of the lower-bound constraint on the means of the model-based predictive distributions for consumer price inflation and real GDP growth. As a benchmark for the assessment, we consider the polar case with the lower bound being recognised, but without state-dependent policies; see the item in the bottom panel of the table. In this case, the means of the predictive distributions fall persistently below the baseline paths over the full horizon of the December 2018 BMPE. The mean effect on inflation builds up gradually and reaches, in absolute value, 0.7 percentage points in the final year of the BMPE horizon, whereas the mean effect on real GDP growth rises to a level of 0.85 percentage points in the middle year of the projection horizon.[15]

The results presented in Panels A to D of Table 3 broadly confirm the findings based on the model-based risk measures, as summarised in Table 1. First, asset purchases and fiscal stimulus, whether implemented in isolation or whether implemented jointly, are able to reduce the mean effects due to the lower bound, albeit to a limited extent (Panel A). Second, strong forward guidance succeeds in reducing the size of the mean effects on inflation and GDP growth to values equal to -0.05 and -0.15 percentage points, respectively (Panel B). The contribution from additional asset purchases is very small. Third, weak forward guidance is noticeably less effective in reducing the mean effects (Panel C). And finally, enhanced forward guidance with strong asset purchases and fiscal stimulus, is almost as effective as strong forward guidance (Panel D).

4 Macroeconomic performance in a low-real-interest-rate world

In the years prior to the financial crisis, and in its aftermath, a large number of model-based studies were carried out using stochastic simulations to gauge the extent to which the effective lower bound on nominal interest rates may deteriorate overall macroeconomic performance. Studies with a focus on the US economy include Reifschneider and Williams (2000), Coenen et al. (2004), Williams (2009) and Chung et al. (2012), whereas Coenen (2003) considers the euro area economy. More recently, heightened concerns about the secular fall in the long-run equilibrium real interest rate have brought about the need to re-assess the incidence and severity of situations where monetary policy is constrained by the lower bound. To make such re-assessment most relevant from a policy perspective, it is important to account for the stabilising role of the non-standard instruments that central banks have adopted in the post-crisis period.

With this in mind, we conduct stochastic simulations with NAWM II to construct *steady-state distributions* for inflation, the output gap and the short-term nominal interest rate under different assumptions concerning the level of the long-run equilibrium real interest rate.[16] Using these steady-state distributions, we first gauge the impact of a lower equilibrium real rate on the ability of monetary policy to stabilise inflation and the output gap when it can only resort to its standard interest-rate instrument subject to the lower-bound constraint. We then proceed and evaluate the extent to which alternative specifications of

[15] As in Table 2, the results for the year 2018 are not shown as they are quantitatively negligible.

[16] Our approach is similar to the approach taken by Kiley (2018), who uses FRB/US, the Federal Reserve Board's semi-structural model of the US economy.

state-dependent forward guidance and asset purchases can ameliorate the adverse effects stemming from the lower-bound constraint and, thereby, improve overall macroeconomic performance. In addition, with the objective of broadening the scope of the evaluation, we also examine the role that state-dependent fiscal stimulus can play as an additional stabilisation instrument when monetary policy is constrained.

4.1 Assessing the efficacy of state-dependent policies

Using NAWM II, our study of the consequences of the lower-bound constraint for overall macroeconomic performance is carried out for different values of the model's annualised steady-state real interest rate, $r^* = 400 \cdot \log(\bar{R}^r)$. Specifically, we consider values for r^* equal to 2%, 1% and 0%, which roughly span the range of values circumscribing the documented secular decline in the long-run equilibrium real interest rate.

Serving as the basis for assessing the efficacy of the alternative state-dependent policies, Table 4 presents a comprehensive set of summary statistics characterising the steady-state distributions obtained from the model for the three different values of r^*. These statistics provide information on the lower-bound incidence, measured by the frequency, i.e. the number of times, the short-term nominal interest rate is at the effective lower bound, and by the (average) duration of a lower-bound event; on the means, the standard deviations and the (average) root mean-squared errors (RMSEs) of inflation and the output gap; and, in addition, on the size of the asset purchases carried out and of the spending-based fiscal stimulus provided when the lower-bound is reached.[17]

Our assessment covers alternative specifications of the state-dependent asset-purchase and fiscal-stimulus policies, as well as alternative assumptions about the effectiveness of state-dependent interest-rate forward guidance; see Section 2 for details. We focus on asset-purchase policies that are not subject to a threshold for the interest-rate shortfall, whereas fiscal stimulus is assumed to always respect a threshold value equal to a one percentage-point shortfall of the annualised short-term nominal interest rate. This assumption reflects the view that fiscal stimulus is likely to be enacted with less ease and immediacy than monetary stimulus. Additional sensitivity analysis concerning the specification of the asset-purchase policy is summarised in Section 4.2 below.

[17] In conducting the stochastic simulations for obtaining the model's steady-state distributions, the lower-bound constraint is imposed at an interest-rate level of -35 basis points, accounting for a small spread between the EURIBOR and the ECB's deposit facility rate, which has been equal to -40 basis points during the period when the model-based exercise was conducted. For further details on the stochastic simulations see Appendix B.

The bottom panel in Table 4 reports summary statistics for the two benchmarks cases with and without taking into account the lower-bound constraint. These statistics suggest that, in a world with a lower long-run equilibrium real interest rate, the lower-bound constraint, if unaddressed, is likely to lead to a significant deterioration of overall macroeconomic performance, as reflected in the inflated RMSEs of the steady-state distributions for inflation and the output gap. The adverse effects due to the lower bound are larger, the lower the equilibrium real rate: As the equilibrium rate falls from 2% to zero, the lower-bound frequency rises from 6% to 16%, while the average duration of the lower-bound episodes increases from 5 to 6 quarters. Even more worryingly, the RMSEs for inflation and the output gap increase more from 2.9% and 8.4% to 7.6% and 20.7%, respectively. These inflated RMSEs reflect both marked shortfalls in the means as well as markedly increased standard deviations of the respective distributions.

As shown in Panel A of the table, state-dependent asset purchases and fiscal stimulus by themselves can redress part of the distortions due to the lower-bound constraint. That is, both strong asset purchases and fiscal stimulus succeed in lowering the RMSEs for inflation and the output gap relative to the constrained benchmark case, even though both the shortfalls in the means of inflation and the output gap and the magnitude of the standard deviations remain sizeable, especially for values of the equilibrium real rate equal to and below 1%. At the same time, the lower-bound incidence, in terms of both frequency and duration, is not very much affected. Fiscal stimulus turns out to be more effective than asset purchases, especially if the equilibrium real rate equals zero and the consequences of the lower-bound constraint are particularly severe. If strong asset purchases are combined with fiscal stimulus, the shortfalls in the means of inflation and the output gap can be reduced much more strongly, namely by more than a half. As a result, and focusing on the extreme case with an equilibrium rate of zero, the average of the RMSEs for inflation and the output gap drops from 14.1% to 7.1%. This involves substantial asset purchases by the central bank resulting in asset holdings of, on average, 16% of (annual) GDP and a sizeable fiscal stimulus of, on average, 0.75% of GDP. In extreme circumstances, however, the size of the asset holdings and of the fiscal stimulus can become far larger, as indicated by the 95% percentile of the respective distribution. In this context it is important to point out that the provision of fiscal stimulus, in general, lessens the need for carrying out large-scale asset purchases. This becomes particularly apparent when the equilibrium real rate is zero, with the mean and the 95% percentile of the asset-purchase distribution cut roughly to two-thirds of the values obtained if the purchases were carried out in isolation.

Panel B shows that strong forward guidance on interest rates is most powerful and can undo the distortionary effects due to the lower bound to the largest extent. In accordance with the intended low-for-longer element, the number of times the short-term nominal interest rate stays at the lower bound does rise noticeably, as does the mean duration. In particular, for an equilibrium real rate of zero the lower-bound frequency rises from roughly 16% to about 25%, while the duration rises from 6 quarters to about 12.5 quarters. Regarding overall macroeconomic performance, as measured by the RMSEs, strong forward guidance gets close to the unconstrained benchmark case, especially if the equilibrium real rate equals 2%. However, for increasingly lower values of the equilibrium rate, the means of the steady-state distributions for inflation and the output gap continue to fall short of the means obtained for the unconstrained benchmark case. Accordingly, the differences in RMSEs are more pronounced. Interestingly, carrying out additional asset purchases does not consistently improve macroeconomic performance. For very low values of the equilibrium rate, the output gap stabilisation performance is moderately strengthened, whereas the performance regarding inflation stabilisation actually weakens somewhat.

Panel C confirms that, as expected, weak forward guidance is considerable less effective than strong forward guidance and results in a worsening of overall macroeconomic performance, as demonstrated by the larger RMSEs. By contrast, as shown in Panel D, enhanced forward guidance brought about by the conduct of strong asset purchases is almost as effective as strong forward guidance. If additional fiscal stimulus is provided, macroeconomic performance is further improved, but only modestly. In this case, the average amount of assets purchased is reasonable, as is the average size of the fiscal stimulus, but the amount of asset purchases needed can still be substantial in extreme circumstances, with the 95% percentile of the purchases being at around 27% of GDP.

To sum up our NAMW II-based study of the efficacy of the alternative state-dependent policies in a low-real-interest-rate world, Figure 4 zooms in on the summary statistics presented in Table 4 and displays the average RMSEs of the steady-state distributions for inflation and the output gap for the different values of the equilibrium real interest rate considered. While not offering new results, the bar charts in the figure provide a simple and effective means of visualising the key findings of our study.

4.2 Further sensitivity analysis

Complementing the findings of our model-based study of the efficacy of alternative state-dependent policies in a low-real-interest-rate environment, Table 5 summarises the results of sensitivity analysis regarding the specification of the state-dependent asset-purchase rule described in Section 2.2. Panel A shows that implementing both moderate and strong asset purchases subject to a threshold equal to a one percentage-point interest-rate shortfall, while retaining the AR(2) component of the rule, leads to a uniform worsening of its stabilisation performance. At the same time, the implied asset purchases turn out to be somewhat smaller in size, whereas the lower-bound incidence is generally somewhat higher. This suggests that delaying the start of asset purchases in a low-interest-rate environment where the standard interest-rate instrument is expected to be stuck at the effective lower bound more frequently is detrimental.

Panel B considers the case of strong asset purchases when the state-dependent rule features an AR(1) component with autoregressive parameter $\rho_a = 0.9$, instead of the benchmark AR(2) specification. As the peak of the central bank's asset holdings is already reached in the initial period, without any further build-up in the absence of a persistent interest-rate shortfall, the overall size of the asset purchases is smaller and the stabilisation performance of the rule is hence worse compared to the benchmark rule with the AR(2) component. In the light of this finding, Panel B also reports the outcomes for a rule with sensitivity parameter $\alpha_a = 2.5$ resulting in "very strong" asset purchases. For this rule, the stabilisation performance is closer to the outcome under the benchmark AR(2) specification, while the implied asset purchases are more sizeable.

To shed some light on the robustness of our findings with regard to the specification of standard interest-rate policy, Table 6 reports the results of additional sensitivity analysis concerning the role of the degree of inertia of the interest-rate rule used in conducting the model-based stochastic simulations. In the analysis, we consider different calibrations of an inertial version of the Taylor (1993) rule, instead of the model's estimated interest-rate rule. Specifically, we examine two alternative cases with "high inertia" (Panel A) and "moderate inertia" (Panel B), corresponding to a coefficient of, respectively, 0.90 and 0.75 on the lagged realised interest rate.[18] In conducting the simulations, we abstract from the state-dependent policies considered in the main analysis and focus on the two benchmark cases with and without the lower-bound constraint being imposed. A first notable result concerns the finding that the lower-bound frequency is noticeably higher for the moderately inertial rule. The reason is that, with less built-in inertia, the interest rate tends to fall more quickly to the lower bound in response to the materialisation of adverse shocks that lower inflation

[18]The estimated lagged-interest-rate coefficient of the model's interest-rate rule, with a value equal to 0.924, is even somewhat larger than the coefficient in the high-inertia case.

and the output gap. A second finding is that, relative to the unconstrained benchmark case, the RMSEs for both inflation and the output gap deteriorate more strongly under the rule with moderate inertia when the lower bound is imposed. This however conceals that the downward bias of inflation is smaller. Finally, and related to the second finding, it is noteworthy that the size of the RMSEs implied by the moderately inertial rule is already larger in the unconstrained benchmark case.

When compared with the findings obtained for the estimated interest-rate rule (see Panel E in Table 4), it is striking that the calibrated rules result in a markedly higher lower-bound incidence, both in terms of frequency and duration. Concerning overall stabilisation performance, the average RMSEs for inflation and the output gap under the calibrated rules exceed the average RMSEs obtained for the estimated rule if the lower-bound constraint is disregarded. This finding reflects the far lower RMSEs for inflation under the estimated rule, whereas the RMSEs for the output gap are only moderately higher. However, if the lower bound is taken into account, the RMSEs implied by the estimated rule are inflated more substantially and exceed the RMSEs under the calibrated rules by a factor which rises inversely with the level of the equilibrium real interest rate. This reflects in part the increasing inflation bias under the estimated rule.

5 Conclusions

The end of the Great Moderation and the secular fall in the equilibrium real interest rate have increased the incidence and the length of periods with nominal interest rates at their effective lower bound and have challenged the flexible inflation targeting regimes with an inflation target of around 2%, which prevail in many advanced economies. In this paper we address this challenge using stochastic simulations with the ECB's recently extended NAWM II. The paper has two main findings. First, it shows that the lower bound, if unaddressed, can have very substantial costs in terms of a worsened macroeconomic stabilisation performance. In the current low-inflation and low-interest-rate environment, the effective lower bound amplifies the impact of adverse shocks on inflation and GDP growth, leading to elevated deflation and recession risks and a noticeable downward bias in the respective predictive distributions. Similarly, with a lastingly lower equilibrium real interest rate, the lower-bound constraint significantly impairs overall macroeconomic performance, substantially inflating the RMSEs of the steady-state distributions for inflation and the output gap under Taylor-type interest-rate rules.

And second, the paper finds that state-dependent policies that kick in when the interest rate is at its lower bound can largely undo these distortionary effects. If fully credible, state-dependent forward guidance, whereby the interest rate is kept low for longer than suggested by the standard interest-rate rule depending on the severity of the recession and the shortfall of inflation, is most powerful. This result may, however, be subject to the so-called forward-guidance puzzle of New Keynesian DSGE models which gives rise to empirically implausible effects of forward guidance on the economy. However, the paper also shows that a combination of imperfectly credible forward guidance, asset purchases and fiscal stimulus is almost equally effective, in particular when asset purchases enhance the credibility of the forward guidance policy through a signalling effect.

Our findings are of relevance for the review of monetary policy frameworks that some major central banks have recently embarked on. On the one hand, they suggest that it is of utmost importance that central banks maintain their approximate 2% inflation buffer in order not to compound the distortions associated with the lower equilibrium real rate. On the other hand, with effective non-standard monetary policies there may be no need to raise the prevailing inflation targets from around 2% to higher values, as suggested by a number of economists. More analysis is, however, needed to investigate the robustness of these findings using different modelling approaches. In particular, our analysis based on NAWM II assumes rational expectations, which enhances the effectiveness of systematic state-dependent monetary and fiscal policies. Examining the performance of such policies under alternative forms of expectations formation is an important item on the future research agenda. Moreover, NAWM II assumes a particular, though empirically plausible, transmission channel of asset purchases and has a relatively simple account of the effects of fiscal spending. The robustness of the main findings with respect to alternative transmission channels of, and synergies between, the different state-dependent policies also needs to be investigated. We leave this for future research.

References

An, S. and F. Schorfheide (2007). Bayesian analysis of DSGE models. *Econometric Reviews 26*(2-4), 113–172.

Anderson, G. (1987). A procedure for differentiating perfect-foresight-model reduced-form coefficients. *Journal of Economic Dynamics and Control 11*(4), 465–481.

Anderson, G. and G. Moore (1985). A linear algebraic procedure for solving linear perfect foresight models. *Economics Letters 17*(3), 247–252.

Andrade, P., J. Galí, H. Le Bihan, and J. Matheron (2018). The optimal inflation target and the natural rate of interest. Banque de France Working Paper No. 670.

Bernanke, B. S. (2017). Monetary policy in a new era. Paper prepared for "Rethinking Macroeconomic Policy", a conference held at the Peterson Institute for International Economics, Washington, DC, October 12.

Bernanke, B. S., M. T. Kiley, and J. M. Roberts (2019). Monetary policy strategies for a low-rate environment. *AEA Papers and Proceedings 109*(May), 421–426.

Bhattarai, S., G. Eggertsson, and B. Gafarov (2015). Time consistency and the duration of government debt: A signalling theory of quantitative easing. National Bureau of Economic Research, Working Paper 21336.

Blanchard, O. J. (2019). Public debt and low interest rates. *American Economic Review 109*(4), 1197–1229.

Blanchard, O. J. and C. M. Kahn (1980). The solution of linear difference models under rational expectations. *Econometrica 48*(5), 1305–1311.

Blanchard, O. J. and L. H. Summers (2019). *Evolution or Revolution? Rethinking Macroeconomic Policy after the Great Recession*. Cambridge, MA: MIT Press.

Boneva, L., R. Harrison, and M. Waldron (2018). Threshold-based forward guidance. *Journal of Economic Dynamics and Control 90*(C), 138–155.

Boucekkine, R. (1995). An alternative methodology for solving nonlinear forward-looking models. *Journal of Economic Dynamics and Control 19*(4), 711–734.

Brand, C., M. Bielecki, and A. Penalver (2018). The natural rate of interest: Estimates, drivers, and challenges to monetary policy. European Central Bank, Occasional Paper Series No. 217.

Calvo, G. A. (1983). Staggered prices in a utility-maximizing framework. *Journal of Monetary Economics 12*(3), 383–398.

Carlstrom, C. T., T. S. Fuerst, and M. Paustian (2012). Inflation and output in New Keynesian models with a transient interest rate peg. Federal Reserve Bank of Cleveland, Working Paper 12-34.

Carlstrom, C. T., T. S. Fuerst, and M. Paustian (2017). Targeting long rates in a model with segmented markets. *American Economic Journal: Macroeconomics 9*(1), 205–242.

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. European Central Bank, Working Paper Series No. 944.

Chung, H. T., É. Gagnon, T. Nakata, M. Paustian, B. Schlusche, J. Trevino, D. Vilán, and W. Zheng (2019). Monetary policy options at the effective lower bound: Assessing the Federal Reserve's current policy toolkit. Board of Governors of the Federal Reserve System, Finance and Economics Discussion Series 2019-003.

Chung, H. T., J.-P. Laforte, D. Reifschneider, and J. C. Williams (2012). Have we underestimated the likelihood and severity of zero lower bound events? *Journal of Money, Credit and Banking 44*(1), 47–82.

Coenen, G. (2003). Zero lower bound: Is it a problem in the euro area? European Central Bank, Working Paper Series No. 269.

Coenen, G., P. Karadi, S. Schmidt, and A. Warne (2018). The New Area-Wide Model II: An extended version of the ECB's micro-founded model for forecasting and policy analysis with a financial sector. European Central Bank, Working Paper Series No. 2200.

Coenen, G., A. Orphanides, and V. Wieland (2004). Price stability and monetary policy effectiveness when nominal interest rates are bounded at zero. *Advances in Macroeconomics 4*(1), Article 1.

Coenen, G. and A. Warne (2014). Risks to price stability, the zero lower bound and forward guidance: A real-time assessment. *International Journal of Central Banking 10*(2), 7–54.

Debortoli, D., J. Galí, and L. Gambetti (2018). On the empirical (ir)relevance of the zero lower bound constraint. Centre for Economic Policy Research, Discussion Paper DP12691.

Del Negro, M., M. Giannoni, and C. Patterson (2012). The forward guidance puzzle. Federal Reserve Bank of New York, Staff Report No. 574.

ECB (2019). Taking stock of the Eurosystem's asset purchase programme after the end of net asset purchases. *Economic Bulletin, Issue 2, Article prepared by Felix Hammermann, Kieran Leonard, Stefano Nardelli and Julian von Landesberger.* European Central Bank, March.

Eichenbaum, M. S. (2019). Rethinking fiscal policy in an era of low interest rates. Northwestern University, Maunscript.

Engen, E. M., T. Laubach, and D. Reifschneider (2015). Effects of the Federal Reserve's unconventional monetary policies. Board of Governors of the Federal Reserve System, Finance and Economics Discussion Series 2015-005.

Fair, R. and J. B. Taylor (1983). Solution and maximum likelihood estimation of dynamic nonlinear rational expectations models. *Econometrica 51*(4), 1169–1185.

Gerali, A., S. Neri, L. Sessa, and F. M. Signoretti (2010). Credit and banking in a DSGE model of the euro area. *Journal of Money, Credit and Banking 42*(S1), 107–141.

Gertler, M. and P. Karadi (2011). A model of unconventional monetary policy. *Journal of Monetary Economics 58*(1), 17–34.

Gertler, M. and P. Karadi (2013). QE 1 vs. 2 vs. 3 . . .: A framework for analyzing large-scale asset purchases as a monetary policy tool. *International Journal of Central Banking 9*(1), 5–53.

Hamilton, J. D., E. S. Harris, J. Hatzius, and K. D. West (2016). The equilibrium real funds rate: Past, present and future. *IMF Economic Review 64*(4), 660–707.

Hartmann, P. and F. Smets (2018). The first 20 years of the European Central Bank: Monetary policy. *Brookings Papers on Economic Activity. Forthcoming*.

Holston, K., T. Laubach, and J. C. Williams (2017). Measuring the natural rate of interest: International trends and determinants. *Journal of International Economics 108*(S1), S59–S75.

Jordà, Ò. and A. A. Taylor (2019). Monetary policy divergence. Paper prepared for the Jackson Hole Economic Policy Symposium on "Challenges for Monetary Polciy", hosted by the Federal Reserve Bank of Kansas City, August 22-24.

Juillard, M. (1994). DYNARE – A program for the resolution of non-linear models with forward-looking variables. Release 1.1, CEPREMAP, Manuscript.

Kiley, M. T. (2018). Quantitative easing and the "new normal" in monetary policy. Board of Governors of the Federal Reserve System, Finance and Economics Discussion Series

2018-004.

Kiley, M. T. and J. M. Roberts (2017). Monetary policy in a low interest rate world. *Brookings Papers on Economic Activity 48*(Spring), 317–372.

Laffargue, J.-P. (1990). Résolution d'un modèle macroéconomique avec anticipations rationnelles. *Annales d'Économie et de Statistique 17*(Jan-Mar), 97–119.

Laubach, T. and J. C. Williams (2016). Measuring the natural rate of interest redux. Board of Governors of the Federal Reserve System, Finance and Economics Discussion Series 2016-011.

Mertens, T. M. and J. C. Williams (2019). Tying down the anchor: Monetary policy rules and the lower bound on interest rates. Federal Reserve Bank of San Francisco Working Paper 2019-14.

Montes-Galdón, C. (2018). Imperfect credibility and the forward-guidance puzzle: An empirical evaluation. Manuscript, European Central Bank.

Nessén, M. and D. Vestin (2005). Average inflation targeting. *Journal of Money, Credit and Banking 37*(5), 837–863.

Rachel, L. and L. H. Summers (2019). On falling neutral real rates, fiscal policy, and the risk of secular stagnation. *Brookings Papers on Economic Activity. Forthcoming*.

Reifschneider, D. (2016). Gauging the ability of the FOMC to respond to future recessions. Board of Governors of the Federal Reserve System, Finance and Economics Discussion Series 2016-068.

Reifschneider, D. and J. C. Williams (2000). Three lessons for monetary policy in a low-inflation era. *Journal of Money, Credit and Banking 32*(4), 936–966.

Sims, E. and J. C. Wu (2019). Evaluating central banks' tool kit: Past, present, and future. Paper presented at the FedListens Conference on "Monetary Policy Strategy, Tools & Communication Practices", hosted by the Federal Reserve Bank of Chicago, June 4-5.

Taylor, J. B. (1993). Discretion versus policy rules in practice. *Carnegie-Rochester Conference Series on Public Policy 39*(1), 195–214.

Vestin, D. (2006). Price-level versus inflation targeting. *Journal of Monetary Economics 53*(7), 1361–1376.

Williams, J. C. (2009). Heeding Daedalus: Optimal inflation and the zero lower bound. *Brookings Papers on Economic Activity 40*(Fall), 1–49.

Appendix A: The New Area-Wide Model

The original NAWM is an open-economy DSGE model of the euro area designed for use in the (Broad) Macroeconomic Projection Exercises regularly undertaken by ECB/Eurosystem staff and for analysis of topical policy issues; see Christoffel et al. (2008) for a detailed description of the model's structure. Its development has been guided by the principal consideration of covering a comprehensive set of core projection variables, including a small number of foreign variables, which, in the form of exogenous assumptions, play an important role in the preparation of the staff projections.

The NAWM features four types of economic agents: households, firms, a fiscal authority and the central bank. 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 (short-term) 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. In doing so, 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 a gradual exchange-rate pass-through. A foreign retail firm in turn combines the exported domestic intermediate goods, with aggregate export demand depending on total foreign demand.

Both households and firms face a number of 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 costs in intermediate-good production. Nominal frictions arise from staggered price and wage-setting à la Calvo (1983), in combination with (partial) dynamic indexation of price and wage contracts to past inflation. In addition, there already exist some stylised financial frictions which however enter the model only in the form of exogenous risk premia.

The fiscal authority purchases the public consumption good, issues domestic bonds, and levies different types of distortionary taxes, albeit at constant rates. 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 central bank sets the short-term nominal interest rate according to a Taylor (1993)-type interest-rate rule, stabilising inflation in line with the ECB's definition of price stability.

The extended version of the NAWM—called NAWM II—includes a rich financial sector which is centered around two distinct types of financial intermediaries that are exposed to sector-specific shocks: (i) funding-constrained "wholesale banks" à la Gertler and Karadi (2011) which engage in maturity transformation and originate long-term loans, and (ii) "retail banks" à la Gerali et al. (2010) which distribute these loans to the non-financial private sector and adjust the interest rate on loans only sluggishly. The long-term loans are required by the non-financial private sector to finance capital investments as in Carlstrom et al. (2017). Furthermore, NAWM II includes a set of no-arbitrage and optimality conditions which govern the holdings of domestic and foreign long-term government bonds by the financial and the non-financial private sector, respectively, building on Gertler and Karadi (2013).

The incorporation of these financial extensions into the original model reflects the three-fold aim pursued in the development of NAWM II, namely: (i) to account for a genuine role of financial frictions in the propagation of economic shocks and policies and for the presence of shocks originating in the financial sector itself, (ii) to capture the prominent role of bank lending rates and the gradual interest-rate pass-through in the transmission of monetary policy in the euro area, and (iii) to provide a structural framework useable for assessing the macroeconomic impact of the ECB's large-scale asset purchases which have been conducted in recent years. In the model, central bank asset purchases of long-term government bonds ease wholesale banks' funding constraint and create (excess) balance sheet capacity that banks can use to extend new credit to the non-financial private sector. As a consequence, lending conditions improve and stimulate private investment. Concomitantly, the lending rate spread and the expected excess return, or *premium*, on long-term government bonds relative to the short-term government bond yield fall and asset valuations rise. This generates windfall gains for the wholesale banks, raising their net worth, and allows them to loosen credit conditions further in a positive feedback loop. The ensuing increase in domestic demand puts upward pressure on firms' marginal cost of production and leads to a rise in domestic prices. The decline in the premium on domestic long-term government bonds comes along with a decrease in the premium on foreign long-term government bonds which is brought about by an instantaneous depreciation of the domestic currency, boosting export demand and increasing import prices.

In estimating NAWM II, the standard Bayesian approach outlined in An and Schorfheide (2007) was followed, which was likewise adopted by Christoffel et al. (2008) for estimating the original version of the NAWM. In doing so, the 18 macro variables that were used as observed variables for estimating the original model were retained, albeit with two important changes: all real variables were transformed into per-capita units, and the estimation sample was extended until 2014Q4, resulting in somewhat larger variances of the model's structural shock processes. In addition, six variables were added to the original set of observables, partly in order to provide useful measurements for identifying the model's financial-sector parameters and shocks.

Appendix B: Solution and simulation methods

In order to obtain the predictive distributions around the December 2018 BMPE baseline projection, we first computed the structural shocks and the state variables of NAWM II for the historical data extended with the projection data. To this end we solved the model 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 applied 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 projection horizon, we then generated 2,500 sequences of random shocks with a sample length corresponding to the projection horizon and 2,500 random realisations of the states.[19] We added the sequences of the random shocks (except for the shocks to NAWM II's interest-rate rule which we set to zero) to the sequence of shocks computed over the projection horizon and used the resulting sequences of shocks, along with the random realisations of the states, to conduct stochastic simulations around the December 2018 BMPE baseline, while imposing the effective lower bound constraint on nominal interest rates and taking into account the threshold values in the specification of the alternative state-dependent asset-purchase and fiscal-stimulus rules.[20] If it were not for these non-linearities, we could use the (log-)linear state-space representation of NAWM II to compute the predictive distributions of the endogenous variables of interest without having to resort to stochastic simulations.[21]

For obtaining the steady-state distributions of NAWM II we follow a similar approach. Based on the population covariance matrix of the structural shocks and the conditional covariance matrix of the states computed at the model's deterministic steady state, we first generated 2,500 sequences of random shocks with a sample length equal to 150 quarters and 2,500 random realisations of initial states. With these ingredients, we then conducted stochastic simulations around the deterministic steady state of the model, while imposing the lower bound constraint and taking into account the threshold conditions of the

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

[20] To ensure stability of the original NAWM in the presence of the lower-bound constraint, Coenen and Warne (2014) allowed fiscal policy to boost aggregate demand to rescue the economy from falling into a deflationary spiral, if deflation becomes so severe that the lower bound eventually restricts the real interest rate at a level high enough to induce a growing aggregate demand imbalance. For the simulations with NAWM II reported in this paper, there was no necessity to allow for such mechanism, and the model could always be solved with the lower-bound constraint being imposed, even though the computation time for obtaining the solution of the model at times increased considerably.

[21] As the stochastic simulations are centred on the structural shocks and the initial states which have been identified with NAWM II for the BMPE projection baseline, it is actually not relevant that the model's (log-)linear state-space representation was used for that purpose even though the effective lower bound was eventually constraining the short-term nominal interest rate in recent years and over the projection horizon. The applied simulation method also implies that all previous and expected policy measures of the ECB, including its asset purchases, are reflected in the shock sequences and the initial states for the BMPE baseline.

state-dependent policy rules. In order to ensure that the steady-state initialisation of the stochastic simulations does not materially influence the properties of the resulting steady-state distributions, we discarded the first 50 realisations of each of the simulated variable paths and retained only the 100 final realisations.

We simulated the non-linear model with the lower-bound constraint and policy thresholds using a computationally efficient and robust algorithm which is implemented in TROLL and based on work by Laffargue (1990), Juillard (1994) and Boucekkine (1995).[22] 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 effective lower bound on nominal interest rates into the model, the variance of future shocks introduces 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 effective lower bound on nominal interest rates binds with greater frequency, the indirect effect is that all agents in the model 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 NAWM II, which has more than one hundred 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.

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

Table 1: Effects of state-dependent policies on deflation and recession risks and on the lower-bound incidence

	Deflation risk	Severity of deflation risk	Recession risk	Conditional deflation risk	Lower-bound incidence
A. No forward guidance					
Asset purchases:					
moderate, w/o threshold	10.54	-2.14	22.23	11.60	37.96
moderate, with threshold	10.73	-2.18	22.50	11.91	38.14
strong, w/o threshold	10.36	-2.07	21.86	11.13	37.76
strong, with threshold	10.70	-2.15	22.46	11.79	38.12
Fiscal stimulus:					
with threshold	10.62	-2.10	22.44	11.57	38.12
w/o threshold	9.46	-1.94	20.35	9.62	37.79
Strong asset purchases w/o threshold and fiscal stimulus:					
with threshold	10.14	-2.00	21.76	10.77	37.75
w/o threshold	9.15	-1.85	19.80	8.83	37.42
B. Strong forward guidance	5.06	-1.30	16.27	3.41	45.46
Strong asset purchases w/o threshold	5.03	-1.29	16.15	3.25	45.43
C. Weak forward guidance	6.44	-1.48	18.42	5.39	37.69
Strong asset purchases w/o threshold	6.33	-1.45	18.09	5.11	37.48
D. Enhanced forward guidance					
Strong asset purchases w/o threshold	5.41	-1.32	16.88	3.71	39.53
Strong asset purchases w/o threshold and fiscal stimulus:					
with threshold	5.40	-1.31	16.84	3.65	39.52
w/o threshold	5.30	-1.30	16.30	3.25	39.56
E. Benchmark: No state-dependent policies					
Lower bound imposed	10.77	-2.21	22.54	11.98	38.16
Lower bound not imposed	4.55	-1.19	14.72	2.00	—

Note: This table reports risk measures which are computed from NAWM II-based predictive distributions for consumer price inflation, real GDP growth and the short-term nominal interest rate. The distributions are derived from stochastic simulations which are centred on the structural shocks and the initial states that the model has identified for the December 2018 BMPE baseline projection. These simulations take into account the effective lower-bound constraint on nominal interest rates and are conducted for alternative specifications of the state-dependent asset-purchase and fiscal-stimulus rules, as well as under alternative assumptions on the effectiveness of state-dependent forward guidance on short-term nominal rates. Consumer price inflation is measured in terms of the private consumption deflator. The short-term nominal interest rate corresponds to the 3-month EURIBOR, and the effective lower-bound constraint is imposed at an interest-rate level of -31.5 basis points, equal to the value of the EURIBOR at the start of the December 2018 BMPE horizon. All risk measures represent relative frequencies and are expressed in percent, except for the measure of the severity of deflation which equals the inflation mean conditional on being in a deflation state.

Table 2: Size of state-dependent asset purchases and state-dependent fiscal stimulus when the lower-bound constraint is binding

	Asset purchases						Fiscal stimulus					
	2019		2020		2021		2019		2020		2021	
	Mean	95%	Mean	95%	Mean	95%	Mean	95%	Mean	95%	Mean	95%
A. No forward guidance												
Asset purchases:												
moderate, w/o threshold	1.13	3.33	2.79	8.42	4.08	12.84	—	—	—	—	—	—
moderate, with threshold	0.11	0.55	0.49	2.24	0.95	4.28	—	—	—	—	—	—
strong, w/o threshold	2.23	6.58	5.44	16.37	7.87	24.65	—	—	—	—	—	—
strong, with threshold	0.22	1.09	0.95	4.39	1.82	8.35	—	—	—	—	—	—
Fiscal stimulus:												
with threshold	—	—	—	—	—	—	0.02	0.11	0.06	0.35	0.10	0.59
w/o threshold	—	—	—	—	—	—	0.17	0.62	0.32	1.21	0.42	1.69
Strong asset purchases w/o threshold and fiscal stimulus:												
with threshold	2.20	6.47	5.32	15.88	7.60	23.62	0.02	0.10	0.05	0.29	0.08	0.49
w/o threshold	1.93	5.70	4.63	13.79	6.59	20.43	0.16	0.60	0.31	1.15	0.40	1.59
B. Strong forward guidance												
Strong asset purchases w/o threshold	1.31	4.24	2.44	8.50	2.86	11.12	—	—	—	—	—	—
C. Weak forward guidance												
Strong asset purchases w/o threshold	1.72	5.09	3.58	10.75	4.46	14.47	—	—	—	—	—	—
D. Enhanced forward guidance												
Strong asset purchases w/o threshold	1.50	4.55	2.90	9.21	3.41	12.07	—	—	—	—	—	—
Strong asset purchases w/o threshold and fiscal stimulus:												
with threshold	1.50	4.51	2.89	9.18	3.39	12.04	0.00	0.01	0.01	0.05	0.01	0.07
w/o threshold	1.42	4.28	2.73	8.68	3.22	11.39	0.06	0.22	0.08	0.35	0.09	0.43

Note: This table reports the size of the central bank's additional asset holdings and the additional fiscal stimulus (expressed as a percentage of annual steady-state GDP) according to alternative state-dependent rules that become active when the short-term nominal interest has fallen to the effective lower bound. The size of the asset holdings and fiscal stimulus are measured by the mean and the 95% percentile of the respective predictive. The results for the year 2018 are not not shown as they are quantitatively negligible. See Table 1 for further explanations.

Table 3: Effects of state-dependent policies on the mean values of consumer price inflation and real GDP growth when taking into account the lower-bound constraint

	Consumer price inflation			Real GDP growth		
	2019	2020	2021	2019	2020	2021
A. No forward guidance						
Asset purchases:						
moderate, w/o threshold	-0.14	-0.44	-0.66	-0.51	-0.80	-0.61
moderate, with threshold	-0.14	-0.46	-0.69	-0.52	-0.84	-0.65
strong, w/o threshold	-0.14	-0.42	-0.63	-0.49	-0.75	-0.55
strong, with threshold	-0.14	-0.45	-0.68	-0.52	-0.83	-0.63
Fiscal stimulus:						
with threshold	-0.14	-0.44	-0.66	-0.50	-0.79	-0.60
w/o threshold	-0.12	-0.36	-0.54	-0.34	-0.62	-0.48
Strong asset purchases w/o threshold and fiscal stimulus:						
with threshold	-0.13	-0.41	-0.60	-0.47	-0.70	-0.50
w/o threshold	-0.11	-0.33	-0.49	-0.31	-0.55	-0.41
B. Strong forward guidance	-0.01	-0.03	-0.05	-0.09	-0.15	-0.11
Strong asset purchases w/o threshold	-0.01	-0.03	-0.05	-0.09	-0.14	-0.11
C. Weak forward guidance	-0.05	-0.14	-0.19	-0.27	-0.37	-0.23
Strong asset purchases w/o threshold	-0.05	-0.13	-0.18	-0.25	-0.33	-0.20
D. Enhanced forward guidance						
Strong asset purchases w/o threshold	-0.02	-0.06	-0.08	-0.15	-0.20	-0.13
Strong asset purchases w/o threshold and fiscal stimulus:						
with threshold	-0.02	-0.06	-0.08	-0.15	-0.19	-0.12
w/o threshold	-0.02	-0.05	-0.07	-0.10	-0.17	-0.12
E. Benchmark: No state-dependent policies						
Lower bound imposed	-0.15	-0.46	-0.70	-0.53	-0.85	-0.67

Note: This table reports the mean effects on the NAWM II-based predictive distributions for consumer price inflation and real GDP growth due to the lower-bound constraint on nominal interest rates. All effects are expressed as percentage-point deviations from December 2018 BMPE baseline values. The results for the year 2018 are not not shown as they are quantitatively negligible. See Table 1 for further explanations.

Table 4: Effects of state-dependent policies under the lower-bound constraint for alternative values of the equilibrium real interest rate

	Lower-bound incidence		Inflation			Output gap			Inflation and output gap	Asset purchases		Fiscal stimulus	
	Frequency	Duration	Mean	Std	RMSE	Mean	Std	RMSE	Average RMSE	Mean	95%	Mean	95%
A. No forward guidance													
Moderate asset purchases w/o threshold													
$r^* = 2\%$	6.02	4.83	1.38	2.52	2.57	-1.79	7.24	7.46	5.02	2.73	13.47	—	—
$r^* = 1\%$	10.60	5.26	0.67	3.67	3.87	-4.29	9.69	10.60	7.23	6.46	36.69	—	—
$r^* = 0\%$	16.51	5.75	-0.65	5.75	6.29	-9.14	13.98	16.70	11.50	13.41	75.82	—	—
Strong asset purchases w/o threshold													
$r^* = 2\%$	5.99	4.70	1.46	2.35	2.39	-1.48	6.82	6.98	4.68	4.62	23.57	—	—
$r^* = 1\%$	10.69	5.09	0.83	3.30	3.47	-3.60	8.76	9.47	6.47	11.18	62.81	—	—
$r^* = 0\%$	16.96	5.56	-0.44	5.22	5.72	-8.00	12.47	14.82	10.27	24.41	136.99	—	—
Fiscal stimulus with threshold													
$r^* = 2\%$	5.94	4.76	1.52	2.26	2.29	-1.38	6.62	6.76	4.53	—	—	0.17	0.80
$r^* = 1\%$	10.41	5.14	1.06	2.92	3.04	-3.09	7.94	8.52	5.78	—	—	0.42	2.50
$r^* = 0\%$	16.32	5.52	0.27	4.05	4.37	-6.28	10.05	11.85	8.11	—	—	0.88	5.19

Note: For different values of the annualised steady-state short-term real interest rate $r^* = 400 \cdot \log(\bar{R}^r)$ (expressed as a percentage), this table reports summary statistics of the NAWM II-based steady-state distributions: the incidence of the lower-bound constraint (measured by the frequency, i.e. the number of times, the short-term nominal interest rate is at the effective lower bound, in percent, and the (average) duration of a lower-bound event, in quarters); the mean, the standard deviation (std) and the (average) root mean-squared error (RMSE) of inflation and the output gap; and the size of the central bank's additional asset holdings and the additional fiscal stimulus (measured by the mean and the 95% percentile of the respective steady-state distribution and expressed as a percentage of annual and quarterly steady-state GDP, respectively). The steady-state distributions are derived from stochastic simulations around the model's non-stochastic steady state. These simulations take into account the lower-bound constraint on nominal interest rates and are conducted for alternative specifications of the state-dependent asset-purchase and fiscal-stimulus rules, as well as under alternative assumptions about the effectiveness of state-dependent forward guidance on short-term nominal rates. Inflation is measured in terms of the private consumption deflator. The short-term nominal interest rate corresponds to the 3-month EURIBOR, and the lower-bound constraint is imposed at an interest-rate level of -35 basis points, accounting for a small spread between the EURIBOR and the ECB's deposit facility rate, which was equal to -40 basis points during the period when the model-based exercise was conducted.

Table 4: Effects of state-dependent policies under the lower-bound constraint for alternative values of the equilibrium real interest rate (cont'd)

	Lower-bound incidence		Inflation			Output gap			Inflation and output gap	Asset purchases		Fiscal stimulus	
	Frequency	Duration	Mean	Std	RMSE	Mean	Std	RMSE	Average RMSE	Mean	95%	Mean	95%
A. No forward guidance (cont'd)													
Strong asset purchases w/o threshold, and fiscal stimulus with threshold													
$r^* = 2\%$	5.88	4.63	1.59	2.12	2.14	-1.07	6.28	6.37	4.26	3.42	19.52	0.12	0.57
$r^* = 1\%$	10.52	4.89	1.19	2.65	2.74	-2.44	7.25	7.65	5.20	7.73	45.03	0.32	1.87
$r^* = 0\%$	16.80	5.30	0.41	3.68	3.97	-5.20	8.93	10.33	7.15	16.12	86.69	0.75	4.41
B. Strong forward guidance													
No asset purchases, and no fiscal stimulus													
$r^* = 2\%$	8.06	8.77	1.86	1.81	1.81	-0.27	5.77	5.78	3.79	—	—	—	—
$r^* = 1\%$	14.78	10.27	1.80	1.93	1.93	-0.68	6.13	6.17	4.05	—	—	—	—
$r^* = 0\%$	24.86	12.64	1.63	2.23	2.25	-1.66	6.81	7.01	4.63	—	—	—	—
Strong asset purchases w/o threshold, but no fiscal stimulus													
$r^* = 2\%$	8.07	8.74	1.86	1.81	1.81	-0.26	5.75	5.76	3.78	0.67	3.27	—	—
$r^* = 1\%$	14.88	10.30	1.80	1.93	1.93	-0.65	6.09	6.12	4.03	1.70	11.65	—	—
$r^* = 0\%$	25.20	12.78	1.60	2.26	2.28	-1.62	6.76	6.95	4.62	4.23	28.64	—	—

Note: See above.

Table 4: Effects of state-dependent policies under the lower-bound constraint for alternative values of the equilibrium real interest rate (cont'd)

	Lower-bound incidence		Inflation			Output gap			Inflation and output gap	Asset purchases		Fiscal stimulus	
	Frequency	Duration	Mean	Std	RMSE	Mean	Std	RMSE	Average RMSE	Mean	95%	Mean	95%
C. Weak forward guidance													
No asset purchases, and no fiscal stimulus													
$r^* = 2\%$	8.65	9.60	1.84	1.85	1.85	-0.36	5.85	5.86	3.86	—	—	—	—
$r^* = 1\%$	15.73	11.09	1.75	2.01	2.02	-0.87	6.29	6.35	4.18	—	—	—	—
$r^* = 0\%$	26.24	13.76	1.53	2.37	2.40	-2.02	7.09	7.37	4.89	—	—	—	—
Strong asset purchases w/o threshold, but no fiscal stimulus													
$r^* = 2\%$	8.63	9.51	1.84	1.84	1.84	-0.33	5.81	5.82	3.83	0.88	4.82	—	—
$r^* = 1\%$	15.79	11.06	1.75	2.00	2.01	-0.81	6.21	6.26	4.13	2.14	15.13	—	—
$r^* = 0\%$	26.54	13.86	1.50	2.39	2.42	-1.92	6.99	7.25	4.84	5.11	34.14	—	—
D. Enhanced forward guidance													
Strong asset purchases w/o threshold, but no fiscal stimulus													
$r^* = 2\%$	8.23	8.97	1.86	1.82	1.82	-0.27	5.76	5.77	3.79	0.72	3.65	—	—
$r^* = 1\%$	15.14	10.55	1.79	1.94	1.94	-0.69	6.11	6.15	4.05	1.79	12.39	—	—
$r^* = 0\%$	25.57	13.08	1.58	2.29	2.31	-1.69	6.81	7.02	4.66	4.41	29.72	—	—

Note: See above.

Table 4: Effects of state-dependent policies under the lower-bound constraint for alternative values of the equilibrium real interest rate (cont'd)

	Lower-bound incidence		Inflation			Output gap			Inflation and output gap	Asset purchases		Fiscal stimulus	
	Frequency	Duration	Mean	Std	RMSE	Mean	Std	RMSE	Average RMSE	Mean	95%	Mean	95%
D. Enhanced forward guidance (cont'd)													
Strong asset purchases w/o threshold, and fiscal stimulus with threshold													
$r^* = 2\%$	8.19	8.94	1.86	1.81	1.81	-0.26	5.74	5.75	3.78	0.68	3.58	0.02	0.07
$r^* = 1\%$	15.04	10.44	1.80	1.92	1.92	-0.63	6.05	6.08	4.00	1.67	11.88	0.06	0.30
$r^* = 0\%$	25.32	12.87	1.63	2.21	2.23	-1.50	6.61	6.78	4.50	3.98	27.17	0.17	1.02
E. Benchmark: No state-dependent policies													
Effective lower bound imposed													
$r^* = 2\%$	6.06	5.04	1.23	2.84	2.92	-2.35	8.07	8.41	5.66	—	—	—	—
$r^* = 1\%$	10.45	5.57	0.36	4.40	4.67	-5.59	11.56	12.84	8.75	—	—	—	—
$r^* = 0\%$	15.87	6.08	-1.15	6.97	7.61	-11.44	17.21	20.67	14.14	—	—	—	—
Effective lower bound not imposed													
$r^* = 2\%$	—	—	1.90	1.75	1.75	0.00	5.62	5.62	3.69	—	—	—	—
$r^* = 1\%$	—	—	1.90	1.76	1.76	0.00	5.75	5.75	3.76	—	—	—	—
$r^* = 0\%$	—	—	1.90	1.77	1.77	0.00	5.91	5.91	3.84	—	—	—	—

Note: See above.

Table 5: Sensitivity of the effects of state-dependent asset purchases under the lower-bound constraint for alternative values of the equilibrium real interest rate

	Lower-bound incidence		Inflation			Output gap			Inflation and output gap	Asset purchases	
	Frequency	Duration	Mean	Std	RMSE	Mean	Std	RMSE	Average RMSE	Mean	95%
A. Benchmark AR(2) process for asset purchases											
Moderate asset purchases with threshold											
$r^* = 2\%$	6.07	4.91	1.34	2.60	2.66	-1.95	7.43	7.68	5.17	2.08	8.72
$r^* = 1\%$	10.62	5.33	0.58	3.84	4.06	-4.63	10.08	11.09	7.58	5.31	30.55
$r^* = 0\%$	16.41	5.78	-0.78	6.01	6.58	-9.72	14.60	17.54	12.06	11.51	68.22
Strong asset purchases with threshold											
$r^* = 2\%$	6.08	4.81	1.40	2.47	2.52	-1.73	7.10	7.31	4.91	3.58	15.53
$r^* = 1\%$	10.70	5.19	0.69	3.57	3.77	-4.14	9.35	10.23	7.00	9.42	53.92
$r^* = 0\%$	16.77	5.63	-0.67	5.65	6.21	-8.95	13.44	16.15	11.18	21.46	127.15
B. AR(1) process for asset purchases											
Strong asset purchases w/o threshold											
$r^* = 2\%$	6.05	4.90	1.33	2.62	2.68	-1.97	7.50	7.75	5.22	2.39	11.35
$r^* = 1\%$	10.60	5.37	0.55	3.93	4.16	-4.74	10.32	11.36	7.76	5.66	31.84
$r^* = 0\%$	16.33	5.85	-0.86	6.23	6.81	-10.01	15.15	18.16	12.49	11.59	66.66
Very strong asset purchases w/o threshold											
$r^* = 2\%$	6.03	4.74	1.42	2.43	2.48	-1.62	7.00	7.19	4.83	5.04	24.59
$r^* = 1\%$	10.72	5.19	0.71	3.55	3.74	-4.00	9.27	10.10	6.92	12.34	68.47
$r^* = 0\%$	16.90	5.68	-0.68	5.75	6.30	-8.88	13.58	16.23	11.26	26.84	153.44

Note: See Table 4 for explanations.

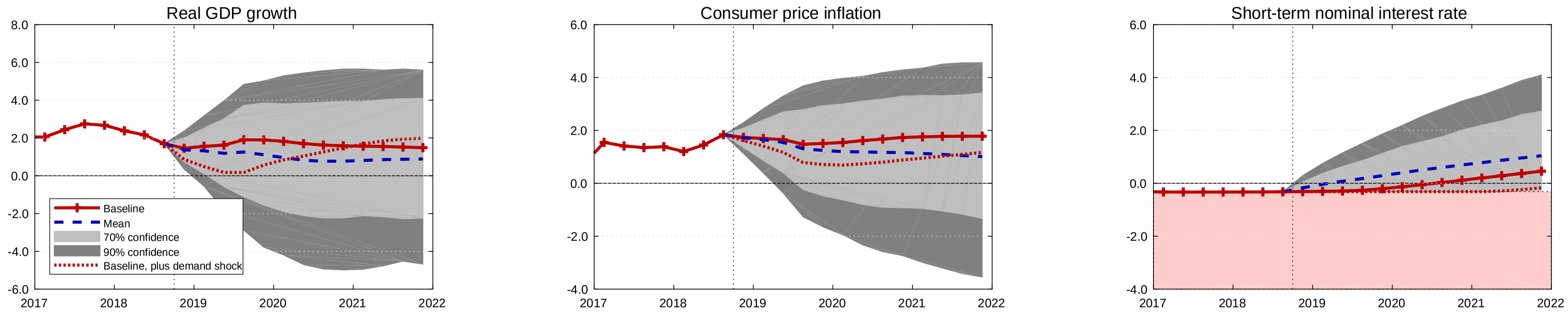
Table 6: Sensitivity of the distortions due to the lower-bound constraint to the specification of the interest-rate rule

	Lower-bound incidence		Inflation			Output gap			Inflation and output gap
	Frequency	Duration	Mean	Std	RMSE	Mean	Std	RMSE	Average RMSE
A. Calibrated Taylor rule with high inertia									
Effective lower bound imposed									
$r^* = 2\%$	13.62	9.64	1.68	4.26	4.27	-1.84	5.30	5.61	4.94
$r^* = 1\%$	19.55	10.84	1.56	4.86	4.87	-3.17	6.10	6.87	5.87
$r^* = 0\%$	26.03	11.93	1.46	5.58	5.60	-5.01	7.08	8.67	7.14
Effective lower bound not imposed									
$r^* = 2\%$	—	—	1.90	3.63	3.63	0.00	4.52	4.52	4.08
$r^* = 1\%$	—	—	1.90	3.82	3.82	0.00	4.69	4.69	4.26
$r^* = 0\%$	—	—	1.90	4.05	4.05	0.00	4.91	4.91	4.48
B. Calibrated Taylor rule with moderate inertia									
Effective lower bound imposed									
$r^* = 2\%$	20.71	9.12	1.70	4.94	4.94	-2.88	5.95	6.61	5.78
$r^* = 1\%$	26.35	10.16	1.66	5.55	5.56	-4.34	6.74	8.02	6.79
$r^* = 0\%$	31.82	11.16	1.63	6.23	6.24	-6.19	7.59	9.79	8.01
Effective lower bound not imposed									
$r^* = 2\%$	—	—	1.90	4.07	4.07	0.00	4.80	4.80	4.44
$r^* = 1\%$	—	—	1.90	4.31	4.31	0.00	5.03	5.03	4.67
$r^* = 0\%$	—	—	1.90	4.60	4.60	0.00	5.33	5.33	4.97

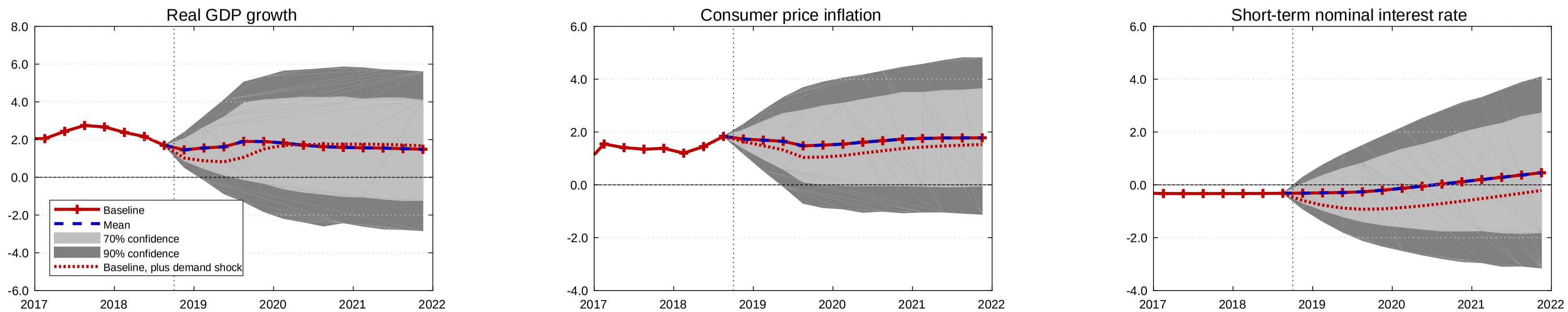
Note: This table reports results regarding the role of the degree of interest-rate inertia on the lower-bound incidence and the steady-state distributions for inflation and the output gap, employing a calibrated inertial Taylor rule: $\tilde{r}_t = \phi_R\, r_{t-1} + (1 - \phi_R)\,(1.5\,\pi_{C,t} + 0.125\,y_t)$, subject to the lower bound, with $\phi_R = 0.90$ ("high inertia") or $\phi_R = 0.75$ ("moderate inertia"). See Section 2.1 for details on the variables entering the rule as well as the implementation of the lower-bound constraint, and Table 4 for explanations of the reported measures.

Figure 1: Predictive distributions around the December 2018 BMPE baseline for real GDP growth, consumer price inflation and the short-term nominal interest rate

A. Effective lower bound recognised



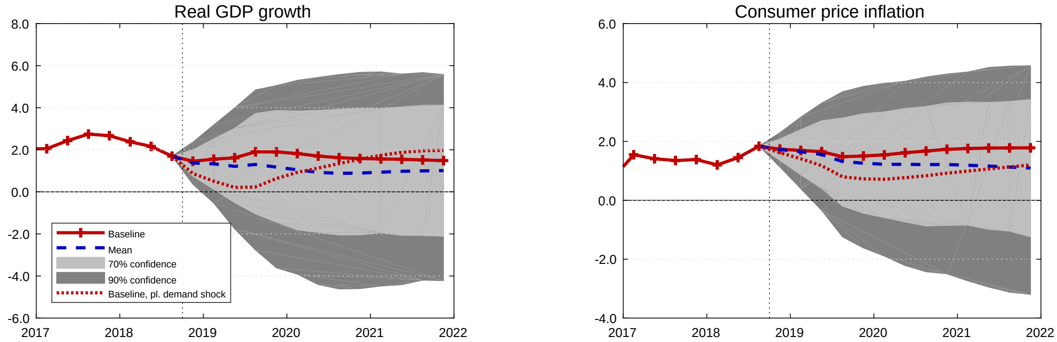
B. Effective lower bound not recognised



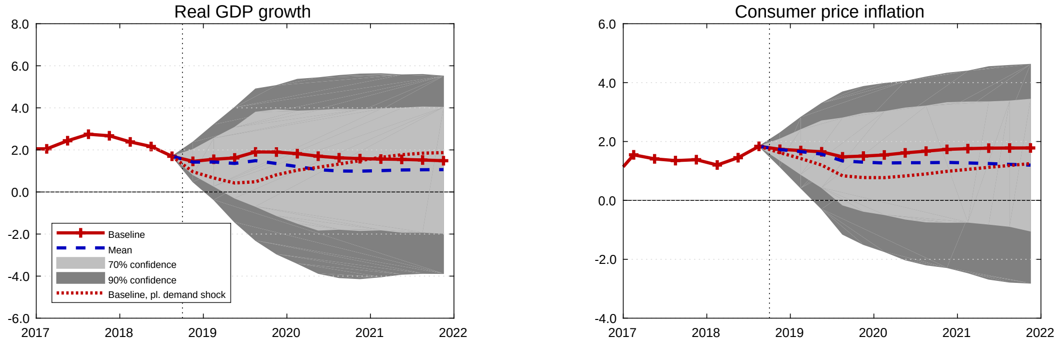
Note: This figure depicts predictive distributions for real GDP growth, consumer price inflation and the short-term nominal interest rate derived from stochastic simulations of NAWM II. The predictive distributions are centred on the structural shocks and the initial states that the model has identified for the December 2018 BMPE baseline projection. Real GDP growth and consumer price inflation (measured in terms of the private consumption deflator) are expressed as annual percentages. The short-term nominal interest rate corresponds to the annualised 3-month EURIBOR, in percent. The lower-bound constraint is imposed at an interest-rate level of -31.5 basis points, equal to the value of the EURIBOR at the start of the December 2018 BMPE horizon; that is, 2018Q4. The simulated additional adverse demand shock corresponds to a one-off domestic risk premium shock of size equal to 1.5 standard deviations and occurs in 2018Q4.

Figure 2: Predictive distributions around the December 2018 BMPE baseline for real GDP growth and consumer price inflation under alternative state-dependent policies

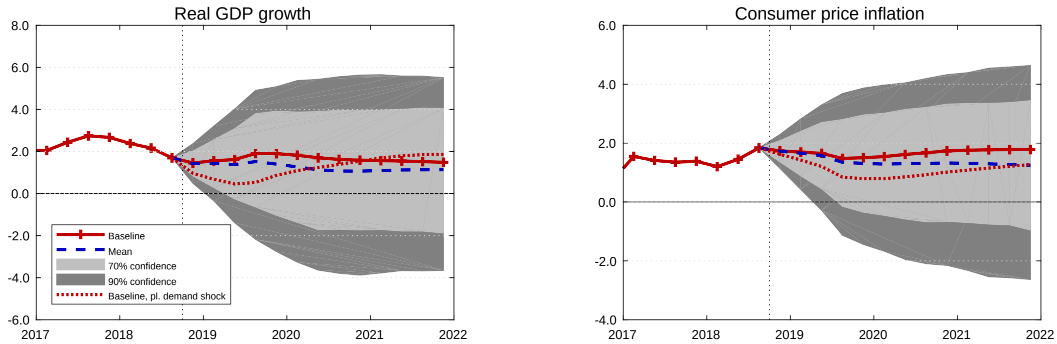
A. Strong asset purchases w/o threshold



B. Fiscal stimulus w/o threshold



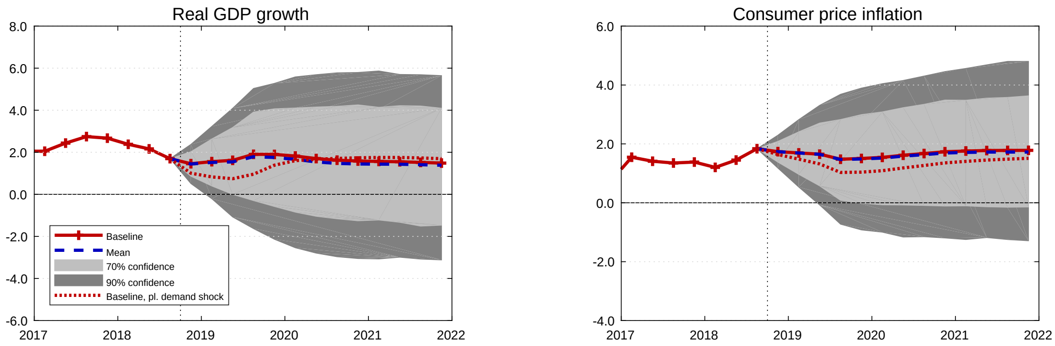
C. Strong asset purchases and fiscal stimulus, both w/o threshold



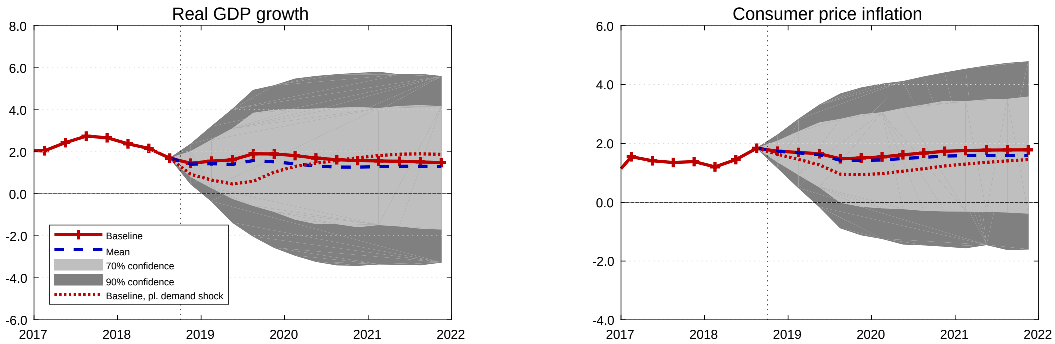
Note: See Figure 1 for explanations.

Figure 2: Predictive distributions around the December 2018 BMPE baseline for real GDP growth and consumer price inflation under alternative state-dependent policies (cont'd)

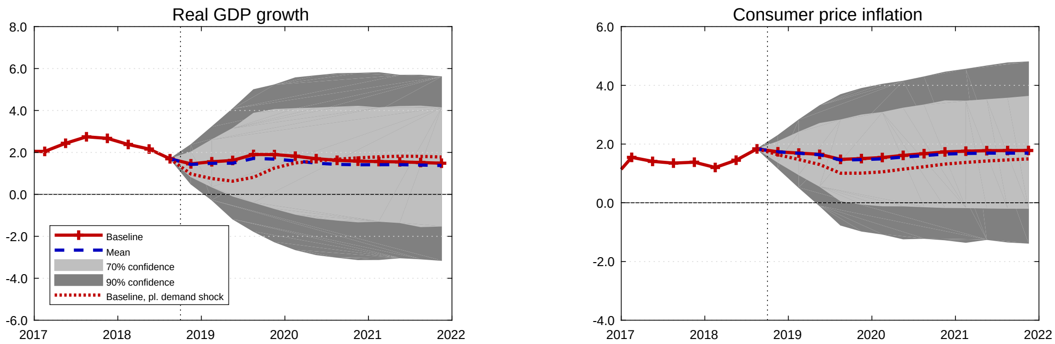
D. Strong forward guidance



E. Weak forward guidance

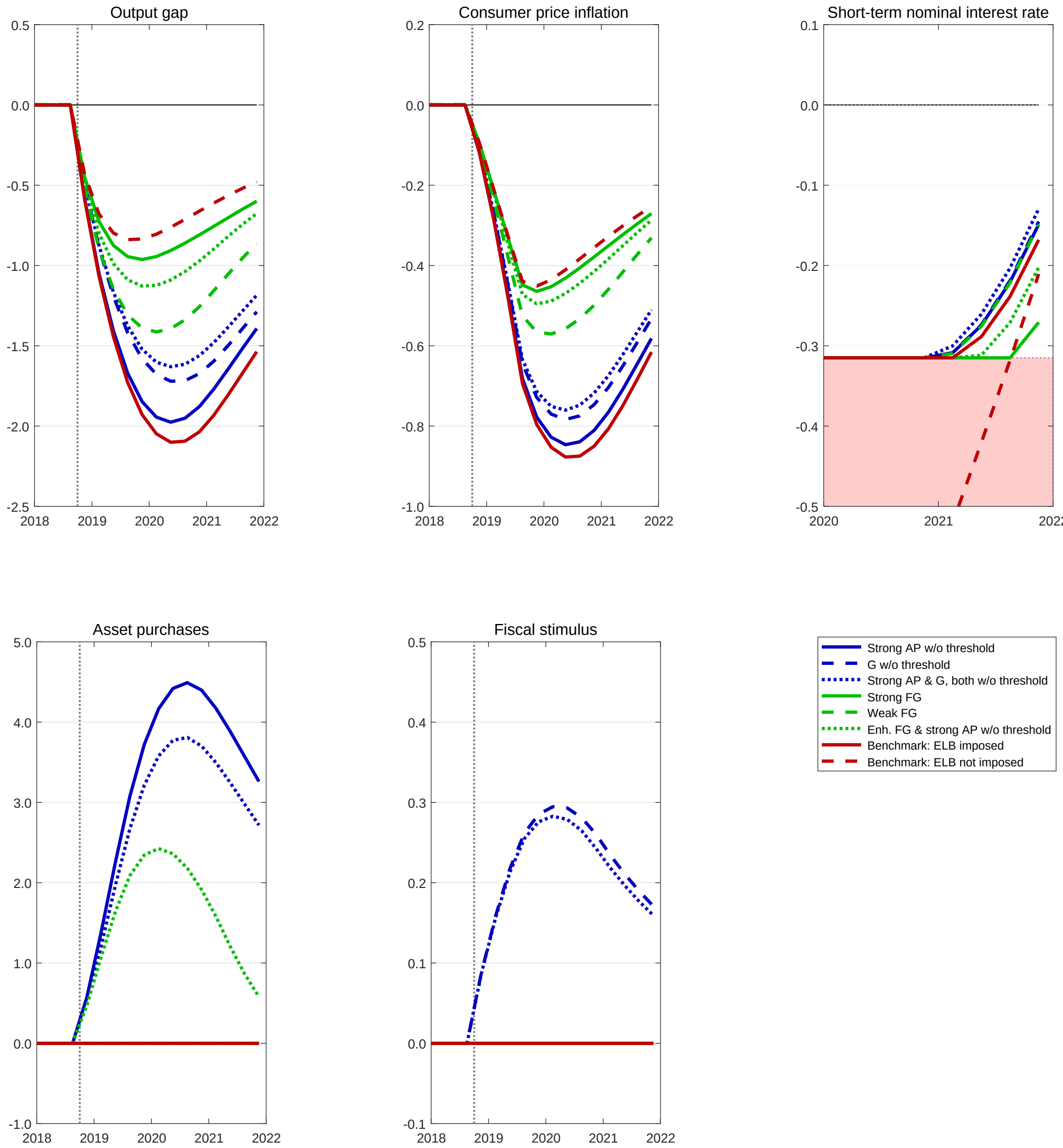


F. Enhanced forward guidance with strong asset purchases w/o threshold



Note: See above.

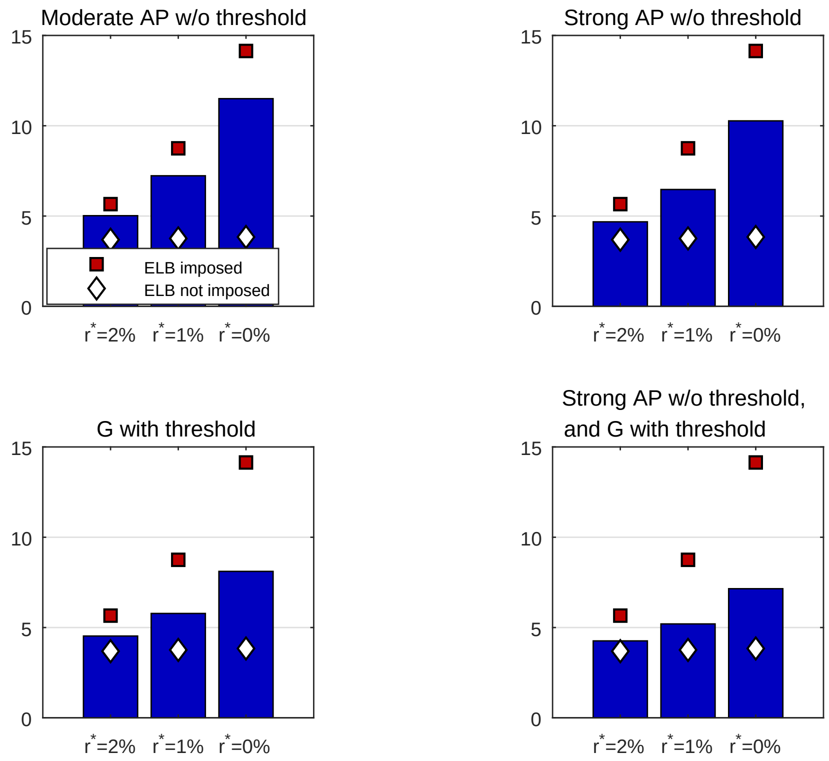
Figure 3: Impact of an additional adverse demand shock on the December 2018 BMPE baseline under alternative state-dependent policies



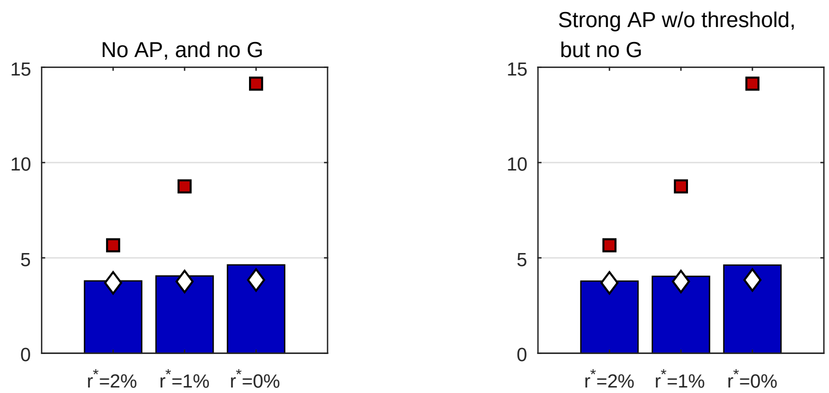
Note: This figure shows NAWM II-based deterministic simulations of an additional adverse demand shock around the December 2018 baseline projection, taking into account the effective lower-bound (ELB) constraint and allowing for alternative state-dependent policy rules governing asset purchases (AP), fiscal stimulus (G) and forward guidance on interest rates (FG). The shock corresponds to a one-off domestic risk premium shock of size equal to 1.5 standard deviations and occurs in 2018Q4. Asset purchases are measured by the central bank's holdings of assets, expressed as a share of annual steady-state GDP, in percent, whereas fiscal stimulus is measured by the amount of government spending, expressed as a share of quarterly steady-state GDP, in percent. The outcomes of the simulations are reported as percentage-point deviations from December 2018 BMPE baseline values, except for the outcomes for the short-term nominal interest rate which are displayed in levels, expressed as annualised percentages.

Figure 4: Overall stabilisation performance of alternative state-dependent policies for different values of the equilibrium real interest rate

A. No forward guidance



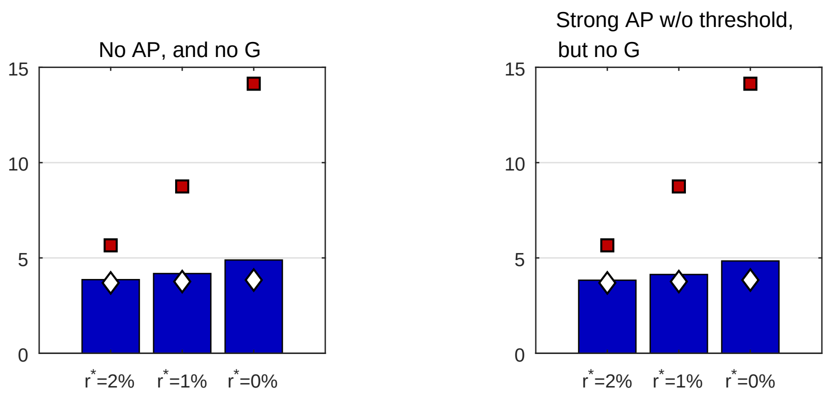
B. Strong forward guidance



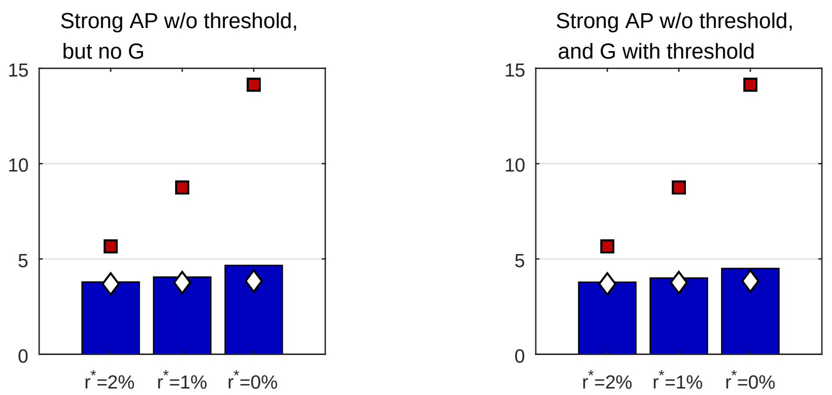
Note: For different values of the annualised steady-state short-term real interest rate $r^* = 400 \cdot \log(\bar{R}^r)$ (expressed as a percentage), this figure displays the average root mean-squared errors (RMSEs) of the NAWM II-based steady-state distributions for inflation and the output gap for alternative specifications of the state-dependent asset-purchase (AP) and fiscal-stimulus (G) rules, as well as under alternative assumptions about the effectiveness of state-dependent forward guidance on short-term nominal rates. The red squares and the white diamonds represent the RMSEs of the two benchmark cases with and without the effective lower bound being imposed.

Figure 4: Overall stabilisation performance of alternative state-dependent policies for different values of the equilibrium real interest rate (cont'd)

C. Weak forward guidance

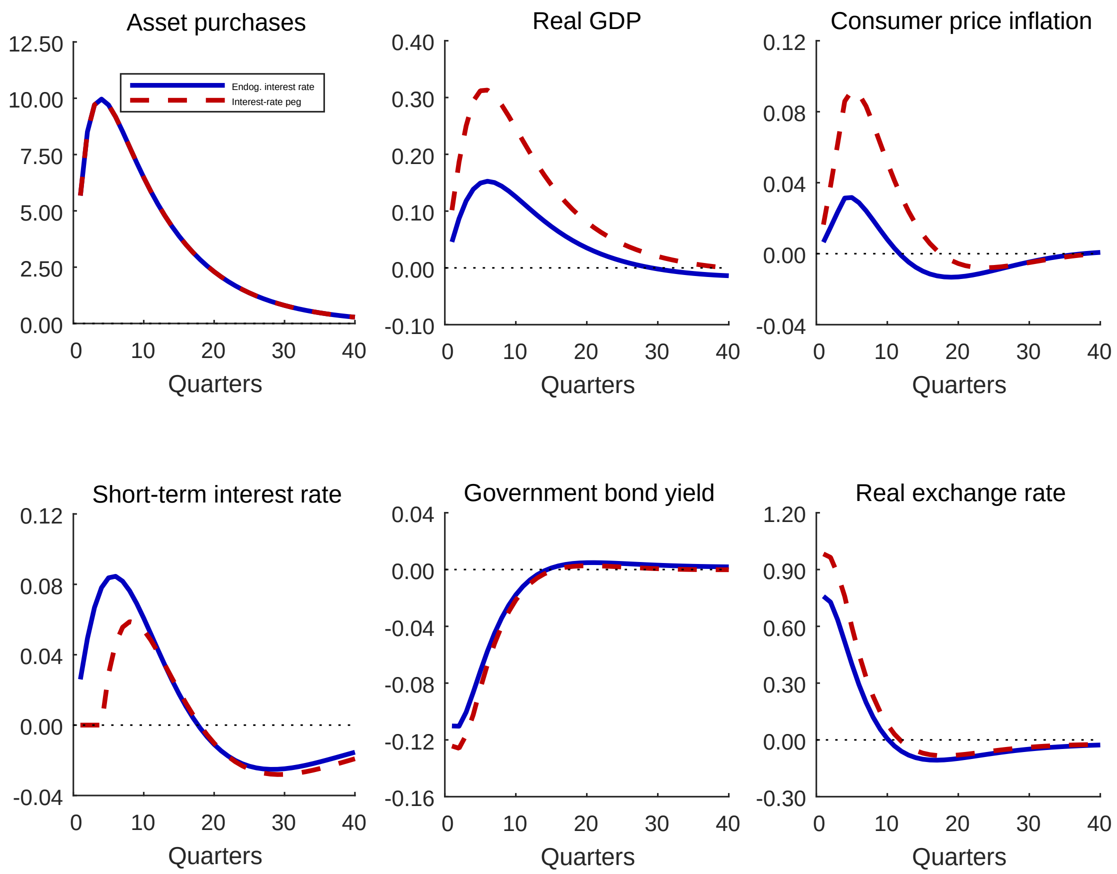


D. Enhanced forward guidance



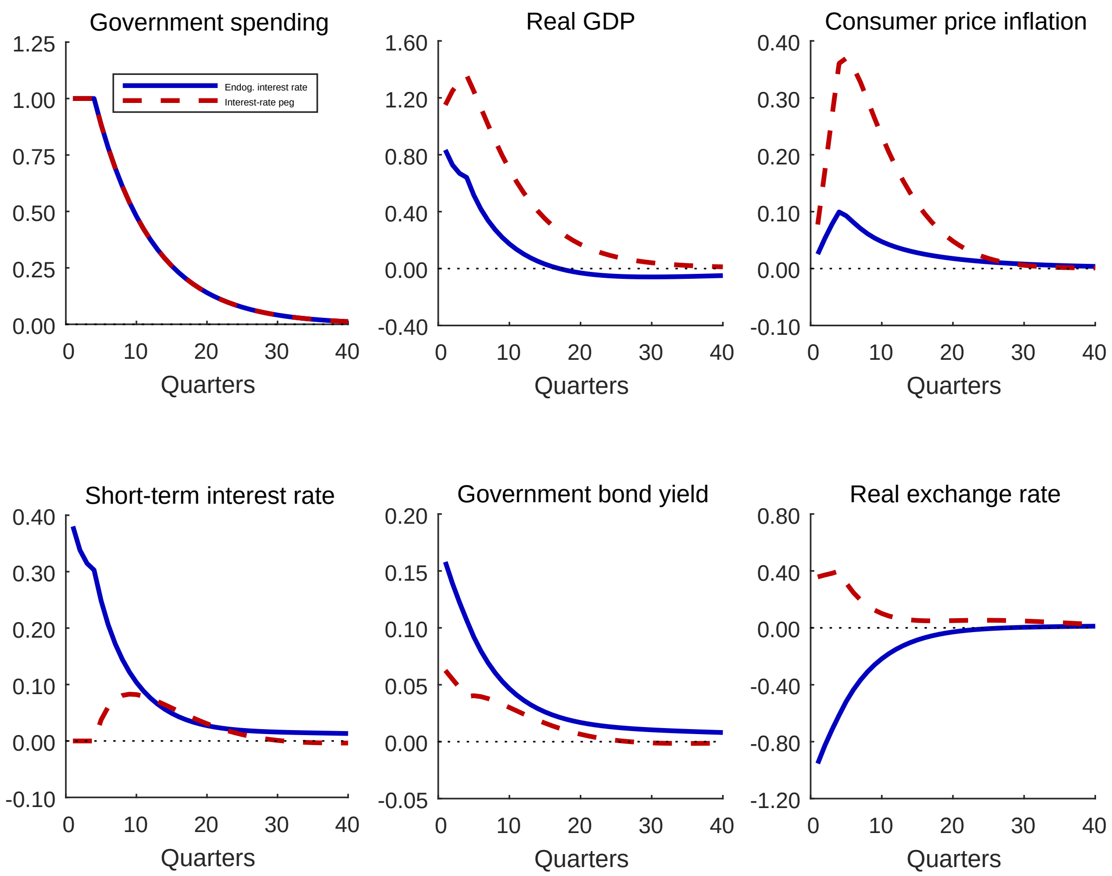
Note: See above.

Figure A.1: Impact of autonomous asset purchases



Note: This figure depicts the effects of an asset purchase shock, which follows the AR(2) process described in equation (3) of Section 2.2. The size of the shock is calibrated such that the central bank's asset holdings reach a peak of 10% of annual steady-state GDP after 4 quarters. The effects are shown for the cases with endogenous interest-rate reaction and with interest rates unchanged for 4 quarters and imperfect credibility of the central bank's announcement thereof. All impulse responses are reported as percentage deviations from the model's steady state, except for the effects on inflation and interest rates which are reported as annualised percentage-point deviations.

Figure A.2: Impact of autonomous fiscal stimulus



Note: This figure depicts the effects of an anticipated increase in autonomous government spending equal to 1% of quarterly steady-state GDP, which lasts 4 quarters and gradually decays thereafter following the AR(1) process described in equation (3) of Section 2.2. The effects are shown for the cases with endogenous interest-rate reaction and with interest rates unchanged for 4 quarters and imperfect credibility of the central bank's announcement thereof. The effects are reported as percentage deviations from the model's steady state, except for the effects on inflation and interest rates which are reported as annualised percentage-point deviations.

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