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Monetary policy strategies for the euro area: optimal rules in the presence of the ELB

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Abstract

We study alternative monetary policy strategies in the presence of the lower bound on nominal interest rates and a low equilibrium real rate using an estimated DSGE model for the euro area. We demonstrate that simple feedback rules that implement inflation targeting result in a binding lower bound one-fourth of the time as well as inflation and output exhibiting large downward biases and heightened volatility. Rule-based asset purchases that are activated once the policy rate reaches the lower bound are not able to fully offset the destabilizing effects of the lower bound if we assume plausible limits on the size of purchases. Makeup strategies, especially average inflation targeting with a long averaging window, perform better than inflation targeting. However, differences in performance across strategies become small if the response coefficients of the feedback rules are optimized. In addition, we find that the benefits of makeup strategies tend to vanish if agents exhibit a degree of inattention to central bank policies as estimated in the data.

Keywords: Monetary policy, effective lower bound, forward guidance, asset purchases, optimal policy, makeup strategies

JEL Classification: E31, E32, E37, E52, E58, E61, E71

Non-Technical Summary

Unlike changes in monetary policy instruments, which are set at policy-meeting frequency, the monetary policy strategy of a central bank is changed rarely. In turn, the setting of policy instruments is guided by the principles established in the monetary policy strategy. This calls for the adoption of a strategy that can adapt to different contingencies.

At the time when the euro area monetary policy strategy was originally designed in the 1990s, the main concern for monetary policy was to anchor inflation at low levels in the face of the inflationary history of previous decades. The period that followed the global financial crisis witnessed a profound change in landscape: the downward trend in the equilibrium real interest rate accelerated and a persistent below-target inflation environment created a concrete risk of de-anchoring of long-term inflation expectations. Addressing low inflation is different from addressing high inflation because the ability of a central bank to provide the necessary accommodation to maintain price stability is constrained by the lower bound on nominal interest rates.

These developments have been common across advanced economies and have generated the urgency to quantify the destabilizing effects of the lower bound on nominal interest rates and to design policy strategies that perform well also in the presence of the lower bound. In practice, inflation targeting – understood as a strategy in which past deviations (undershootings or overshootings) of inflation compared to an inflation target are treated as bygones – is taken as benchmark and the properties of alternative strategies are assessed via model simulations as a sort of laboratory experiment.

We focus on the euro area using an estimated dynamic stochastic general equilibrium model that allows for a trend in the equilibrium real interest rate.

Under the assumption of a 2% inflation target and a level of the real rate in line with estimates for the euro area, we find that Taylor-type policy rules typically taken to represent inflation targeting lead the lower bound to bind one fourth of the time. In addition, inflation and the output gap exhibit large downward biases and heightened volatility.

We find that asset purchases are not able to fully offset the downward biases in inflation and the output gap when we impose plausible limits on the size of asset purchases. We reach similar conclusions when we allow for moderately negative policy rates.

This motivates the search for alternative policy strategies. We focus on a class of policy rules that belongs to makeup strategies – whereby past under(over)-shootings of inflation are not treated as bygones but they influence future policy – and a class that belongs to asymmetric inflation targeting. Within makeup strategies, we consider average inflation targeting (AIT), price level targeting (PLT) and nominal GDP targeting (NGDPT). We find that makeup strategies perform much better than inflation targeting when strategies are implemented via simple policy rules as typically calibrated in the economic literature. However, these calibrations are somewhat arbitrary. When we optimise the value of the response coefficients in the policy rules, the differences in performance with respect to inflation targeting and across makeup strategies are greatly reduced. *Prima facie* this finding suggests that, in empirically plausible models, makeup strategies are not the only way to improve upon standard policy rules.

In addition, we document that the benefits of makeup strategies rely critically on the credibility of the central bank because in the face of the lower bound such strategies require to make promises of lower-for-longer policy rates. Using empirical estimates proxying for credibility – suggesting that policy actions occurring more than 4-5 years out into the future hardly affect agents' current behaviour – we show that lower-for-longer policies may exert only little traction in an empirically plausible model. The reason is that it requires to make promises extending far into the future. This is especially the case if the new policy is adopted in conditions in which the yield curve is rather flat, a situation that prevailed at the time the ECB decided on its new policy strategy in July 2021.

1 Introduction

At the time when the euro area monetary policy strategy was originally designed in the 1990s the main concern for monetary policy was to anchor inflation at low levels in the face of the inflationary history of the previous decades. The decade that followed the global financial crisis witnessed a profound change in landscape: the downward trend in the equilibrium real interest rate accelerated (see, among others, Holston, Laubach, and Williams, 2017 and Brand and Mazelis, 2019) and a persistent below-target inflation environment created a concrete risk of de-anchoring of long-term inflation expectations. Addressing low inflation is different from addressing high inflation because the ability of the central bank to provide the necessary accommodation to maintain price stability is constrained by the lower bound on nominal interest rates.

These developments have a global dimension and have generated interest in the stabilization properties of alternative policy strategies vis-à-vis inflation targeting, where the latter is understood as a strategy in which past undershootings (or overshootings) of inflation are treated as bygones. For instance, Kiley and Roberts (2017) and Bernanke, Kiley, and Roberts (2019), among others, consider the effects of policy strategies such as average inflation targeting (AIT) and price level targeting (PLT), which share the property that the central bank promises to keep rates lower for longer when the economy hits the lower bound. Most of this literature has limited the analysis to simple feedback rules, has not considered non-standard policy measures, and has focused on performance over the longer run paying lower attention to the prevailing macroeconomic conditions at the time of implementation of a new strategy. We contribute to filling these gaps by making four main contributions to the literature.

First, we estimate a DSGE model for the euro area to study alternative monetary policy strategies in an environment with the lower bound on nominal interest rates and low equilibrium real interest rate. Most of the literature has focused on the U.S. — for contemporaneous and independent work using an estimated model of the euro area instead, see Coenen, Montes-Galdón, and Schmidt (2021) and Erceg, Jakab, and Lindé (2021). The model employed in this study is a medium-scale DSGE model building on Smets and Wouters (2007), extended to include QE and time variation in the equilibrium real rate. The latter is modelled in line with Holston, Laubach, and Williams (2017) as a function of long-run growth and an idiosyncratic component. In addition, we construct the output gap as trend output gap, as this better reflects (revealed) preferences of central banks compared to the flex price output gap of Smets and Wouters (2007).[1] We impose the lower bound and run stochastic simulations to study the implications of different

[1]See Adolfson, Laseen, Linde, and Svensson (2011) for a discussion of different notions of the output gap relevant for actual policy making.

values of the inflation target and the equilibrium real rate. Under the assumption of a 2% inflation target and a level of the real rate in line with estimates for the euro area, we find that feedback rules typically taken to represent flexible inflation targeting lead the lower bound to bind one fourth of the time, as well as to inflation and the output gap to exhibit large downward biases and heightened volatility.

Second, we include non-standard monetary policy measures. These instruments have played an important role in actual policy making since the global financial crisis and it may be expected that they can help overcome the destabilizing effects of the lower bound. We represent large scale asset purchases as governed by a rule prescribing to employ asset purchases once the policy rate reaches the lower bound. We find that asset purchases are not able to fully offset the downward biases in inflation and the output gap when we impose plausible limits on the size of asset purchases. We reach similar conclusions when in addition we allow the central bank to set interest rates at moderately negative levels as observed in the euro area in the last few years. We conclude that non-standard measures do not eliminate the need for rethinking the inflation targeting framework.

Third, we compare alternative policy strategies, focusing on average inflation targeting (AIT) with different lengths of the backward averaging window, price level targeting (PLT), nominal GDP targeting (NGDPT) and asymmetric inflation targeting. We implement these strategies via simple feedback rules in the spirit of, among others, Kiley and Roberts (2017) and Bernanke, Kiley, and Roberts (2019), in turn building on earlier work by for instance Orphanides and Wieland (1998), Reifschneider and Williams (2000) and Williams (2009). We find that AIT, PLT and NGDPT perform much better than inflation targeting when strategies are implemented via simple rules as typically calibrated. But we contribute to the literature by computing optimal simple rules and showing that the differences in performance with respect to inflation targeting and across makeup strategies are greatly reduced when we use optimized response coefficients.[2]

Fourth, while early literature has typically assumed that the policy strategy is fully credible and well understood, see for instance Kiley and Roberts (2017), we contribute to the research pointing to the crucial role of expectations formation in determining the performance of makeup strategies, see Bernanke, Kiley, and Roberts (2019), Amano, Gnocchi, Leduc, and Wagner (2020), Budianto, Nakata, and Schmidt (2020), and Busetti, Neri, Notarpietro, and Pisani (2021).[3] We show that policy promises of lower-for-longer embedded in makeup strategies increase in power the more the model suffers from excess sensitivity of inflation to interest rate expectations – the forward guidance puzzle. We find

[2]Optimal policy in the presence of the lower bound is analysed in stylised models in, among others, Eggertsson and Woodford (2003) and Adam and Billi (2006), and optimal simple rules for temporary price level targeting for the US are studied in Hebden and López-Salido (2018).

[3]Honkapohja and Kaushik (2020) and Bodenstein, Hebden, and Winkler (2019) study the transition to PLT in a learning environment at the lower bound.

that the degree of inattention to the central bank's promises found in the data — which implies that policy actions occurring more than 4-5 years out into the future hardly affect agents' current behaviour (see de Groot et al., 2021b) — implies that lower-for-longer policies can exert little traction. This is especially the case if the new policy is adopted in conditions in which the yield curve is rather flat, admittedly a situation that prevailed at the time the ECB decided on its new policy strategy in July 2021. When the yield curve is flat at the level of the lower bound over a long horizon, to be able to provide meaningful accommodation via lower-for-longer promises it is necessary to flatten out the yield curve at very long horizons. But at such horizons, policy promises have little impact.

The paper is organised as follows. Section 2 presents the model and the estimation results. Section 3 discusses the methodology we use to compare the performance of alternative policy strategies. Section 4 presents the properties of inflation targeting in an environment with the lower bound and low equilibrium real rate. Section 5 extends the analysis to include non-standard policy measures. Section 6 studies the performance of alternative strategies represented via simple feedback rules. Section 7 computes optimized simple rules and compares their performance. Section 8 computes fully optimal policy and analyses the role played by the excess sensitivity of inflation to interest rate expectations in determining the effects of lower-for-longer promises. Section 9 presents conclusions.

2 Model specification and estimation

The backbone of the model is the DSGE model of Smets and Wouters (2007), which we modify along three dimensions.[4] First, we add permanent technology shocks that lead to a unit root process for the level of technology. This allows us to define the output gap in terms of deviations of output from its long-run stochastic trend, whereby potential output is the trend output level as in Adolfson, Laseen, Linde, and Svensson (2011). Also, this generates a possible source of time variation in the equilibrium real interest rate (see below). Specifically, the production function of the intermediate firms features both permanent (Z_t) and stationary technology shocks (A_t)

$$Y_t = \varepsilon_t^a (K_t^s(i))^{\alpha} (Z_t L_t(i))^{1-\alpha} - Z_t \Phi. \tag{1}$$

Potential output grows at the rate of technological progress $g_{z,t}$

$$ln(Z_t/Z_{t-1}) = g_{z,t} = \rho_{g_z} g_{z,t-1} + \eta_t^{g_z}. \tag{2}$$

To make the model stationary we detrend all real variables by the level of productivity, Z_t.

[4]The complete model is summarized in Appendix A. It also draws on Maih, Mazelis, Motto, and Ristiniemi (2021).

Second, following Corbo and Strid (2020), we introduce a time-varying equilibrium real interest rate (r_t^*) as a time-varying intercept in the policy rule. We assume it is a function of trend output growth and a reduced-form non-growth component, η_t^n, similar to Holston, Laubach, and Williams (2017)

$$r_t^* = \rho^{rn} r_{t-1}^* + \theta^{rn} g_{z,t-1} + \varepsilon_t^n. \tag{3}$$

For a high value of ρ^{rn}, this process allows to capture highly persistent movements in interest rates as seen in the data while still reverting to the steady state that is consistent with structural parameters.

Given that the model is log-linearised, in the structural equations we simply replace all instances featuring the interest rate with the gap between the interest rate and the nominal neutral rate R_t^*, that is:

$$R_t^{gap} = R_t - R_t^*, \tag{4}$$

where $R_t^* = r_t^* + \pi_t^*$ and π_t^* is the inflation target, which we will assume in the estimation to be constant and thus we write it as a parameter in what follows.

Monetary policy is assumed to follow a Taylor-type rule such that the annualised nominal interest rate, R_t, is set to respond to deviations of inflation from the inflation target and the trend output gap

$$R_t = R_t^* + \rho^r (R_{t-1} - R_{t-1}^*) + (1 - \rho^r) \left[\alpha_\pi (\pi_t - \pi^*) + \alpha_y y_t)\right] + \varepsilon_t^m. \tag{5}$$

Note that the output gap, y_t, is already detrended with the technological progress Z_t at which potential output grows. Hence y_t can be interpreted as a "Beveridge–Nelson cycle" output gap, which allows inference on medium-term growth prospects by measuring the expected degree of economic growth above and below trend levels (Kiley, 2013). The nominal neutral interest rate enters the policy rule as a time-varying intercept. In the estimation we allow the neutral rate to vary, but in the simulations we shift its level permanently by setting ρ^{rn} to 1, and θ^{rn} to 0 and applying a shock of a magnitude that the equilibrium real rate immediately reaches the desired level, effectively rendering it a parameter.

Third, we introduce central bank asset purchases in a simple way whereby they reduce the interest rate faced by the households. As a result, the interest rate gap in the presence of asset purchases becomes also a function of asset purchases:[5]

[5]This approach is in the spirit of Harrison (2017), who introduces portfolio adjustment costs in a canonical New-Keynesian model where QE operates through the portfolio balance channel, and of shadow

$$R_t^{gap} = R_t - R_t^* + \xi^{qe} qe_t \tag{6}$$

The quantitative easing term and the rule governing asset purchases are described in Section 5.

The model is estimated on euro area data over the sample 1995Q1 to 2020Q1. Since the sample includes the period in which the policy rate has been nearing the lower bound, we use the shadow rate constructed in De Rezende and Ristiniemi (2023) as empirical counterpart to the model's short-term rate. Details on the data are provided in Appendix A.

We divide the model's parameters in two sets. One set comprises all parameters in common with Smets and Wouters (2007), as well as those related to trend output growth and the neutral rate process. A subset of those parameters is kept fixed while the others are estimated using Bayesian methods. The parameters and their values are reported in Appendix B and C.

The second set of parameters is related to the impact of asset purchases. Although these parameters could be estimated together with the other parameters of the model, we calibrate them so as to be in line with the elasticities found in a comprehensive Eurosystem's staff assessment of the impact of asset purchases. In our simulations purchasing 30% of the stock of eligible long-term bonds results to approximately 0.7 percentage point peak increase in inflation.[6] We see this calibration approach as a way to limit the extent to which our findings about the performance of alternative monetary policy strategies may be driven by parameters for which there is no consensus in the literature.

3 Methodology to quantify the impact of alternative policy strategies

We assess the properties of alternative monetary policy strategies by computing the unconditional probability distributions for inflation, the output gap and the short-term nominal interest rate, in the spirit of Bernanke, Kiley, and Roberts (2019). These distributions are obtained by carrying out stochastic simulations around the non-stochastic

rate models where the effect of asset purchases on the term structure of interest rates is translated to a decline in the short rate.

[6]Specifically, Altavilla, Lemke, Linzert, Tapking, and von Landesberger (2021), who review the estimated impact of the ECB's asset purchases on euro area inflation across a range of studies, find that an asset purchase shock of 10% of GDP leads to a cumulative change in inflation of between 0.3 and 0.7 percentage points (interquartile range) over a three year horizon. At a debt/GDP ratio in the euro area of 86%, as measured at the end of the first quarter of 2020 (see Eurostat news release on 22 July 2020), such a shock corresponds to asset purchases on the order of 12% in terms of share of the stock of sovereign bonds.

steady state, taking into account the non-linearity of the lower bound. We assume that the euro area is hit in each period by disturbances that are randomly drawn from the estimated distribution of shocks. As the sample period extends until 2020Q1, we capture the shocks that occurred during the global financial crisis and the sovereign debt crisis but not the COVID-19 pandemic, which may otherwise inject extreme volatility.

We activate all shocks with the exception of the monetary policy shocks, measurement errors and shocks to the non-growth component of r_t^* —we explain the rationale below. This leaves us with eight active shocks. Given this large number of shocks, we follow Kiley and Roberts (2017) and Bernanke, Kiley, and Roberts (2019) and do not account for the precautionary motive associated with the non-linearity generated by the lower bound.[7] We implement the lower bound constraint on the policy rate and the size-limit on asset purchases (when activated) using the extended path algorithm (Fair and Taylor, 1983).

We run 2000 simulations of 150 periods discarding the first 50 periods each time. Statistics are computed over all retained simulations.[8] The simulations are repeated for different values of the inflation target and r^*, with and without non-standard policy measures, and for alternative policy strategies. To ensure comparability, the same sequences of shocks are used across exercises, although with 2000 simulations the specific shock series do not play a relevant role.

To facilitate the comparison across alternative policy strategies, changes in r^* are implemented in a way that does not affect the structural parameters of the economy. Specifically, to compute the implications of different steady-state levels of the real interest rate, the literature has used changes in the discount factor or trend output growth (in models with a trend component), or a combination of those. But changing the value of these parameters may lead to different implications for the model dynamics, which may not be supported by the data and may affect the comparison across specifications. We instead apply a one-time shock to the non-growth component of the equilibrium real rate, and no shocks thereafter.[9] By setting ρ^{rn} to 1, this adjustment leads to a permanent level shift in the natural rate. A cross-check of this approach to adjust the equilibrium real rate with other ways of adjustment via deep parameters suggests that simulations behave

[7]The computational time increases exponentially with the number of shocks in the model, see Adjemian and Juillard (2016). For an analysis in which agents display precautionary motives, see for instance Maih, Mazelis, Motto, and Ristiniemi (2021), who quantify the impact of the precautionary motive from the lower bound in an estimated DSGE model for the euro area.

[8]For random seeds that embody highly contractionary realisations of shocks, the economy may get stuck in a liquidity trap where the simulation method is unable to establish the outcome of economic dynamics. This is akin to the "contractionary black hole" of Eggertsson and Giannoni (2020). In computing the statistics we remove highly contractionary outcomes that lead to a decline of inflation of more than -10 percentage points below the target, that is, deflationary scenarios of below -8% inflation are excluded. Therefore, our results may underestimate the distortions created by the lower bound.

[9]This is consistent with Holston, Laubach, and Williams (2017), who find that the idiosyncratic component of r_t^* explains a large part of its decline.

similarly to an approach that reduces trend growth or increases the household discount factor (see Figure 9 in the Annex for a comparison), but without having to take a stance on the source of adjustment nor without the risk of changing model dynamics that rely on these two parameters.

4 Stabilization properties of an inflation targeting strategy

We start with assessing the properties of a benchmark policy rule that can be considered as an approximation of flexible inflation targeting because past deviations of inflation from target (shortfalls or overshoots) are treated as bygones:

$$\text{IT:} \qquad R_t = \rho(R_{t-1}) + (1-\rho)\left(R^* + \alpha_\pi(\bar{\pi}_t^{(4)} - \pi^*) + y_t^{gap}\right) \tag{7}$$

where R_t is the short-term real interest rate, and R^* is the (annualised) equilibrium interest rate,[10] $\bar{\pi}_t^{(4)}$ is the annual consumer price inflation rate where $\bar{\pi}_t^{(4)} = \sum_{i=1}^{4} \pi_{t-i+1}$, and y_t^{gap} is the output gap. In our benchmark calibration we set the annual inflation target, π^*, equal to 2%, $\rho = 0.85$ and $\alpha_\pi = 1.5$. This rule is equivalent to the inflation targeting rule in Kiley and Roberts (2017).

When the policy rate is at the effective lower bound (ELB), Equation (7) describes the shadow interest rate, R_t^{Taylor}, that would prevail were the policy rate not restricted by the lower bound. The actual interest rate faced by the economic agents is instead R_t:

$$\begin{aligned} R_t^{Taylor} &= \rho(R_{t-1}^{Taylor}) + (1-\rho)\left(R^* + \alpha_\pi(\bar{\pi}_t^{(4)} - \pi^*) + y_t^{gap}\right), \\ R &= \max(-ELB, R_t^{Taylor}). \end{aligned} \tag{8}$$

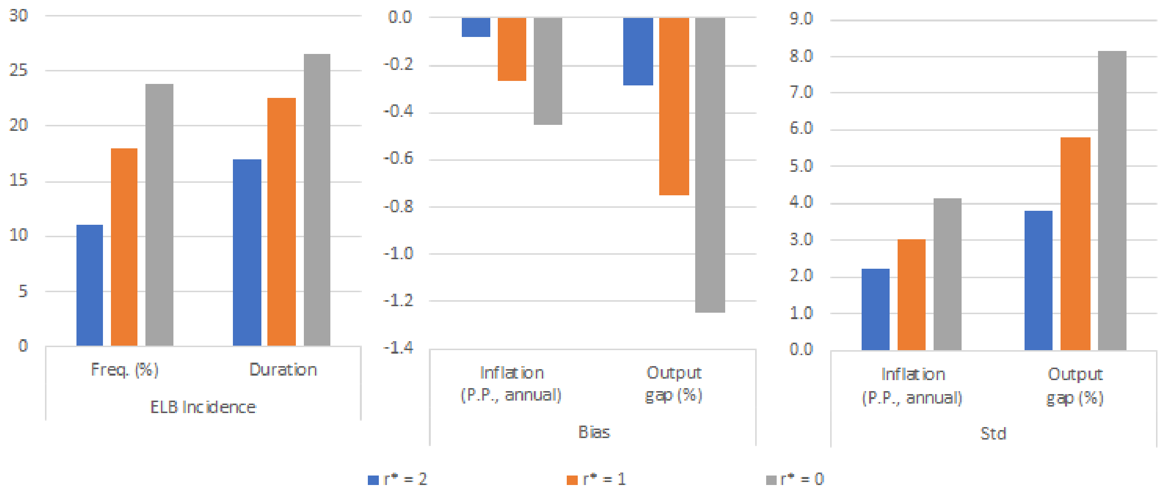
The lower bound is imposed at 0% and it is assumed that the only monetary policy instrument available to the central bank is the short-term interest rate—these assumptions are relaxed in the following sections.

Figure 1 displays the stabilisation properties of the inflation targeting rule for $\pi^* = 2\%$ and different levels of r^*. Assuming that r^* is 2%, the frequency of hitting the zero lower bound is 11% and the average duration of the lower bound is 17 quarters.[11] The lower bound generates a downward bias in inflation and the output gap of 0.1 percentage points and 0.3 percent, respectively. It also leads to heightened volatility.

[10] For simplicity we rewrite R_t^* as a parameter in all the equations in this section because in the simulations we add a shock to the non-growth component of r_t^* in the first period, and none thereafter, such that r_t^* and thus R_t^* are shifted permanently to the desired level.

[11] See Table 5 in the Annex for results in tabular form.

Figure 1: Impact of alternative levels of r^* assuming $\pi^* = 2\%$



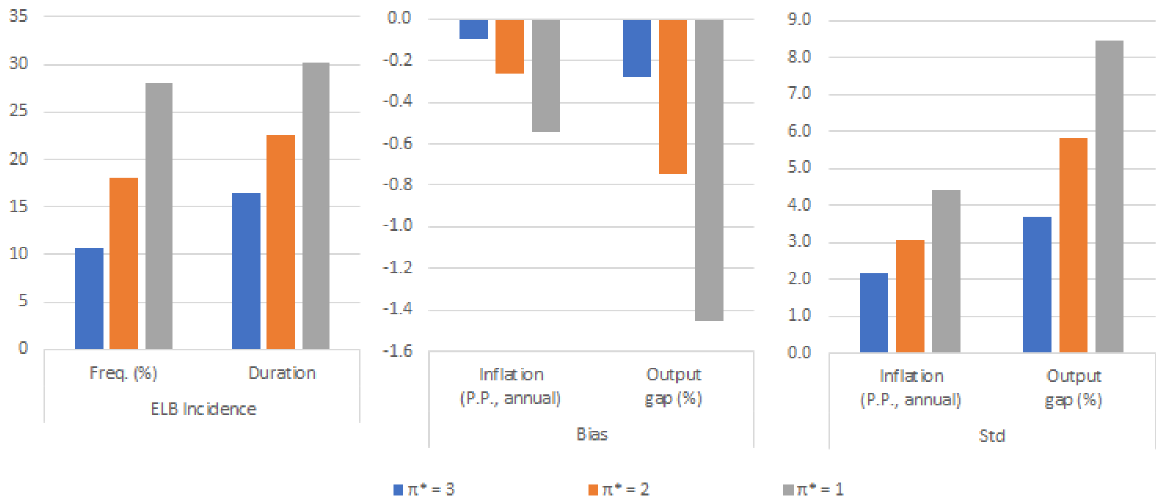
Note: *The figure displays statistics for the lower bound incidence as well as the bias in and the standard deviation of inflation and the output gap. The inflation bias is computed as the difference between mean inflation and the inflation target. The steady-state distributions are computed from stochastic simulations around the non-stochastic steady state. The ELB is set at* 0%.

With r^* equal to 1% the frequency of hitting the zero lower bound increases to 18% and the average duration of the lower bound becomes 23 quarters. The downward bias in inflation and the output gap is 0.3 percentage points and 0.8 percent, respectively. Assuming that r^* is equal to 0%, which is consistent with recent estimates for the euro area (Brand, Bielecki, and Penalver, 2018), the frequency of hitting the zero lower bound rises to almost a quarter of the observations, and the average duration of the lower bound increases to 27 quarters. Inflation falls short of the target by 0.5 percentage points and the output gap by 1.3 percent. The standard deviation of inflation and the output gap increases the lower the real interest rate is: when r^* is 0%, it becomes about twice as large compared to the case in which r^* is 2%.

An increase in the inflation target can remedy the distortions introduced by the zero lower bound, while a reduction makes them worse. Figure 2 shows that an increase in the inflation target to 3% would result in similar macroeconomic outcomes as the case where r^* increases from 1% to 2%. Assuming an inflation target at 1% and r^* at 1% delivers a downward bias in inflation close to 0.6 percentage points and in the output gap to about 1.5 percent.[12]

[12]The results for an inflation target at 1% should be treated with caution because a significant number of simulations do not converge due to the more extreme outcomes they produce. Therefore, the statistics we report underestimate the distortionary effects of the lower bound.

Figure 2: Impact of alternative levels of the inflation target, assuming $r^* = 1\%$



Note: *The figure displays statistics for the lower bound incidence, inflation and the output gap. The inflation bias is computed as the difference between mean inflation and the inflation target. The steady-state distributions are computed from stochastic simulations around the non-stochastic steady state. The ELB is set at* 0%*.*

5 Allowing for non-standard measures

In this section we analyse whether non-standard measures can offset the distortionary effects of the zero lower bound. We focus on negative interest rates and large scale asset purchases.

As regards negative rates, we allow the interest rate to be cut to -0.5%. We select this value as it is the lowest level to which the ECB has cut its interest rate to date. Figure 3 (blue bars) shows the effect of allowing for negative rates assuming an inflation target of 2%. We set the level of r^* to 0.5%, which is in the range of recent estimates of r^* for the euro area. Lower values of r^* would exacerbate further the destabilisation effects of the lower bound under an inflation targeting strategy. We find that the inflation bias is about 0.3 percentage points and the bias in the output gap is 0.7 percent. This result exemplifies that allowing for (mildly) negative rates alone is not sufficient to counteract the adverse effects of the lower bound, and the central bank would need to use additional non-standard measures such as large scale asset purchases to deliver on its target.

As regards large scale asset purchases, we consider three alternative QE rules. In all cases the central bank's balance sheet evolves according to an AR(2) process. This process allows for a gradual build-up of the central bank's portfolio, mimicking the practice typically followed by central banks to make an initial announcement about the size of the purchases while building up the portfolio gradually over time. We define QE as purchased assets as a share of long-term EA bonds. The first rule allows for asset purchases to be conducted also when the interest rate is above the lower bound. We label this rule "permanent QE". The amount of asset purchases is assumed to be a function of the prevailing inflation gap:

$$qe_t = \rho^{qe1} qe_{t-1} - \rho^{qe2} qe_{t-2} - \theta^{qe}(\bar{\pi}_t^{(4)} - \pi^*). \tag{9}$$

The second rule features asset purchases only once the policy rate reaches the lower bound. We label this rule "QE at ELB". The amount of purchases depends indirectly on inflation and the output gap via their impact on the interest rate rule, reminiscent of the state-dependent asset purchasing rule in Coenen, Montes-Galdón, and Smets (2020). However, when the interest rate reaches the ELB, the Taylor rule would call for additional rate cuts if inflation and output fall short of their targets, opening up an interest rate gap. The lower the Taylor rule interest rate is relative to the ELB, the more asset purchases the central bank carries out:

$$qe_t = \rho^{qe1} qe_{t-1} - \rho^{qe2} qe_{t-2} + \tau^{qe} max(0, R_t - R_{t-1}^{Taylor}). \tag{10}$$

The third rule is similar to the second one but we impose a limit to the size of purchases that the central bank can carry out. We set the limit to 50% of the stock of bonds. We label this rule "QE at ELB (50% limit)":

$$qe_t = min(50, \rho^{qe1} qe_{t-1} - \rho^{qe2} qe_{t-2} + \tau^{qe} max(0, R_t - R_{t-1}^{Taylor})). \tag{11}$$

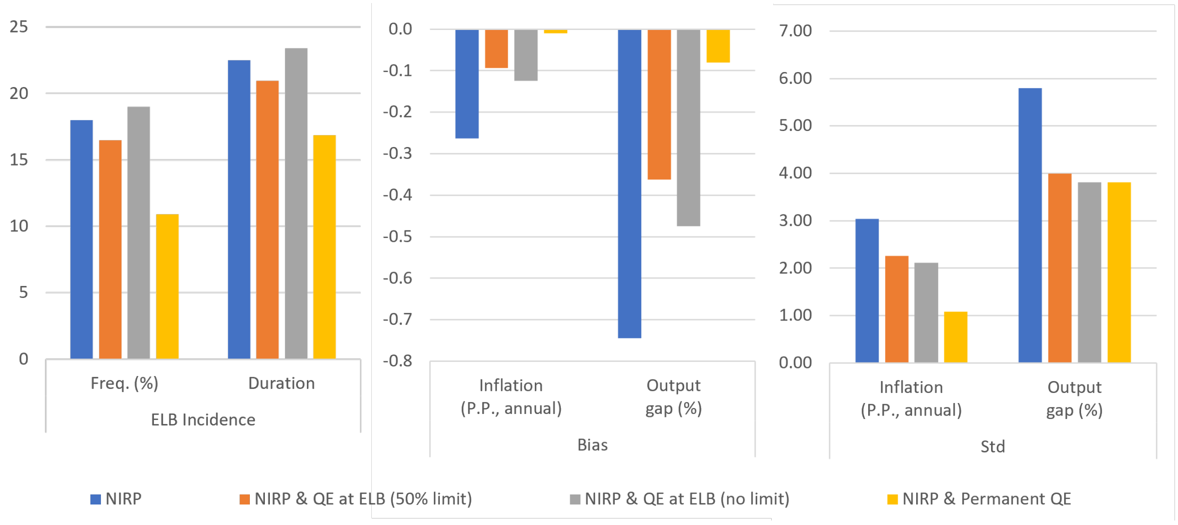
In the simulations we assume an inflation target of 2%, a level of r^* of 0.5% and a level of the ELB at -0.5%.

Figure 3 shows that if we allow the central bank to employ asset purchases once the interest rate reaches the ELB and we do not impose any limit to the size of the central bank's asset holdings (Equation (10)), we find that average inflation bias is 0.1%, see grey bars.[13]

If we impose an asset-purchase limit at 50% of the stock of bonds, as specified in the third rule (Equation (11)), the inflation bias is 0.1%. This however represents an underestimation of the true inflation bias because many runs do not converge compared to the case where there is no upper bound to asset purchases. Were we to include only the same converged simulations in both cases, inflation bias with a 50% limit on asset purchases would be four basis points lower than without the limit.

[13]See Table 6 in the Annex for results in tabular form.

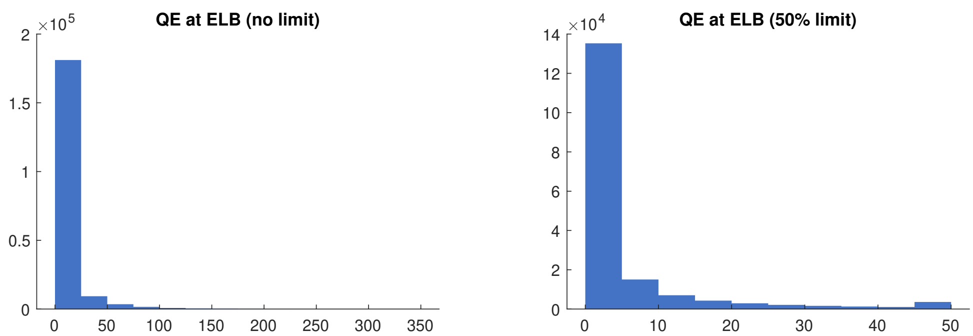
Figure 3: Impact of non-standard measures, assuming $\pi^* = 2\%$ and $r^* = 0.5\%$



Note: *The inflation bias is computed as the difference between mean inflation and the inflation target. The steady-state distributions are computed from stochastic simulations around the non-stochastic steady state. NIRP stands for negative interest rate policy, assumed to allow the policy rate to reach -0.5%. QE is modelled as an endogenous rule that is activated: (i) at the lower bound and with no purchase limits (labelled in the figure as QE at ELB (no limit)), or (ii) at the lower bound but with a purchase limit at 50% (labelled as QE at ELB (50% limit), or is available at all times (labelled as Permanent QE).*

To further investigate the role played by imposing limits to the size of QE, Figure 4 shows the distribution of the size of asset purchases as a percentage of the stock of euro area bonds in the case of no limit to purchases (LHS panel) as well as the case with 50% limit (RHS panel). In the large majority of cases, the purchases are below the 50% limit. However, there are instances in which very large purchases would be required even in excess of 100%. These results show that NIRP & asset purchases activated once the policy rate reaches the ELB are not sufficient to overcome the downward inflation bias under plausible parameterizations of the purchasable amounts.

Figure 4: Histograms of QE with and without upper limit of 50%



If instead we allow the central bank to employ asset purchases also away from the ELB and we do not impose size limits to the amount of purchases, as specified in the rule in Equation (9), Figure 3 shows that asset purchases in combination with NIRP can almost fully offset the inflation bias (yellow bars). However, making QE a standard policy tool to be used also in normal times is a step that no central bank has taken so far.

6 Alternative monetary policy strategies: evaluation based on simple policy rules

Given our finding that under an inflation targeting strategy non-standard measures would not be able to address the distortions caused by the ELB if plausible limits are imposed, in this section we assess the stabilization properties of alternative monetary policy strategies. We consider two types of strategies and we abstract from asset purchases.

The first type rests on dropping the assumption that past inflation shortfalls (overshoots) are bygones. Differently from inflation targeting (IT), inflation under-(over-)shooting would then call on the central bank to aim for inflation above (below) the target for some time in the future. This practice has the potential to be especially useful at the lower bound because the central bank cannot provide additional easing via further cuts of the policy rate at that moment whereas it can promise additional easing to be delivered in the future when the lower bound episode ends. We consider average inflation targeting (AIT), price-level targeting (PLT) and nominal GDP targeting (NGDPT). We follow the approach of Bernanke, Kiley, and Roberts (2019) and Chung, Gagnon, Nakata, Paustian, Schlusche, Trevino, Vilán, and Zheng (2019), among others, in specifying the policy strategy in terms of a simple policy rule, whereby an additional term is added to the inflation targeting rule.

Under AIT the average inflation gap is computed over the previous T years:

$$\text{AIT:} \qquad R_t = \rho R_{t-1} + (1-\rho)\left(R^* + \alpha_\pi(\bar{\pi}_t^{(4)} - \pi^*) + y_t^{gap} + \alpha_{AIT}(\bar{\pi}_t^{(4T)} - \pi^*)\right) \quad (12)$$

where the superscript T on $\bar{\pi}_t^{(4)}$ is the length of the averaging window in years. We set $\rho = 0.85$, as in our IT rule, $\alpha_\pi = 1$, and $\alpha_{AIT} = T$. In our simulations we consider two alternative windows, $T = 4$ years and $T = 8$ years.

The PLT strategy can be seen as a form of AIT where the length of the averaging window is infinitely long:

$$\text{PLT:} \qquad R_t = \rho R_{t-1} + (1-\rho)\left(R^* + \alpha_\pi(\bar{\pi}_t^{(4)} - \pi^*) + y_t^{gap} + \alpha_{PLT}(p_t - p_t^*)\right) \quad (13)$$

where p_t is the price level, and p_t^* is the price-level target, such that $p_t^* = p_{t-1}^* + \pi^*$. We set $\rho = 0.85$, $\alpha_\pi = 1$, and $\alpha_{PLT} = 1$.

Under NGDPT the central bank responds to the gap between the actual and the target nominal GDP paths, where the target is based on deterministic real growth, estimated in euro area data to be 1.1% annually, and the price-level target:

$$\text{NGDPT:} \qquad R_t = \rho R_{t-1} + (1-\rho)\left(R^* + \alpha_\pi(\bar{\pi}_t^{(4)} - \pi^*) + y_t^{gap} + \alpha_{NGDPT}(y_t + p_t - (y_t^* + p_t^*))\right) \tag{14}$$

where $y_t + p_t$ is nominal GDP and $y_t^* + p_t^*$ is the target path for nominal GDP. We set $\rho = 0.85$, $\alpha_\pi = 1$, and $\alpha_{NGDPT} = 1$.

If the length of the averaging window is equal to 1, AIT collapses to IT, except that a positive value of the coefficient in front of the additional AIT term would increase the overall responsiveness of monetary policy to inflation. This highlights that the comparison across strategies carried out using simple rules may be unsatisfactory. It remains unclear the extent to which better performance of, say, AIT compared to IT is due to a stronger response to inflation under AIT, irrespective of the makeup element, or is indeed due to the makeup element, or a combination of the two. We nevertheless follows this approach because it is the typical one followed in the literature, but we relax it in the next section.

The second type of policy strategy that we consider is asymmetric inflation targeting (aIT). The policy response to inflation is made stronger when inflation is below target. In the absence of the lower bound, this generates an upward inflation bias. However, in the presence of the lower bound it has the potential to offset the downward bias in inflation generated by the lower bound:

$$\text{aiT:} \qquad R_t = \rho R_{t-1} + (1-\rho)\left(R^* + y_t^{gap} + \alpha_\pi(\bar{\pi}_t^{(4)} - \pi^*) + \mathbf{I}_{\bar{\pi}_t^{(4)} < \pi^*}\alpha_{aiT}(\bar{\pi}_t^{(4)} - \pi^*)\right) \tag{15}$$

We set $\rho = 0.85$, $\alpha_\pi = 1.5$, and $\alpha_{aiT} = 1$.

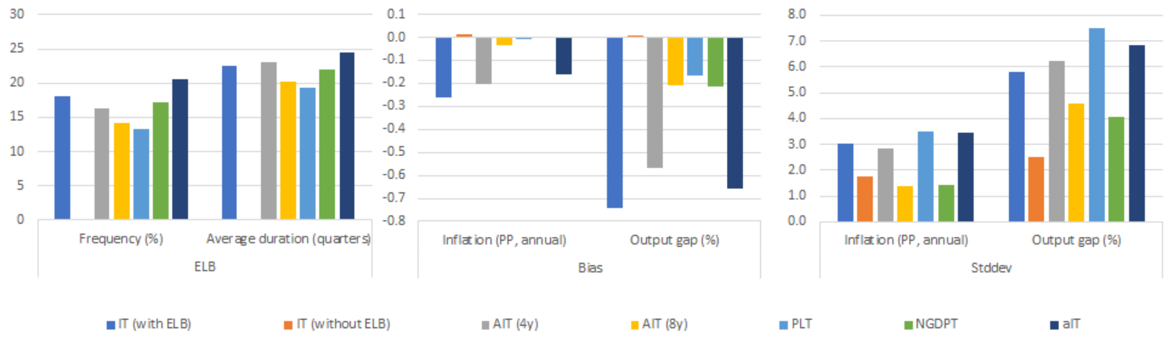
We evaluate the stabilization properties of the policy strategies using stochastic simulations and employing the same sequences of shocks we have used to evaluate IT. We set $\pi^* = 2\%$, $r^* = 0.5\%$ and we impose the ELB at -0.5%.

Figure 5 demonstrates that all the alternative strategies help reduce the distortions generated by the lower bound and perform better than IT.[14] If the makeup approach is well understood by the public and agents are forward looking as in our model, the expectation that the central bank will provide in the future additional easing that will lead inflation to overshoot to compensate for past inflation shortfalls can have an immediate accommodative effect. PLT and NGDPT deliver the lowest inflation bias across the alternatives. However, PLT generates relatively high volatility in the output gap. The reason is that monetary policy has to tighten significantly to compensate for the higher

[14] See Table 7 in the Annex for results in tabular form.

price level caused for instance by a markup shock. The 8-year AIT rule fares better than PLT in terms of volatilities, while it is only marginally worse in terms of biases. The 4-year AIT rule performs much worse than the 8-year AIT both as regards biases and volatilities. The performance of the asymmetric policy rule is similar to the 4-year AIT. In terms of frequency of hitting the ELB and average duration of ELB episodes, the lowest values are reached by PLT and the highest by NGDPT.

Figure 5: Impact of alternative monetary policy strategies, assuming $\pi^* = 2\%$ and $r^* = 0.5\%$



Note: *The figure displays statistics for inflation and the output gap. The inflation bias is computed as the difference between mean inflation and the inflation target. The steady-state distributions are computed from stochastic simulations around the non-stochastic steady state. The ELB is set at -0.5%.*

To rank the policy strategies we summarize their performance using the period loss function:

$$L = (\pi_t^4 - \pi^*)^2 + \omega_y (y_t - y^*)^2 + \omega_R (\Delta R_t)^2. \tag{16}$$

We set the weight on output, ω_y, at 0.25 and the weight on smoothing, ω_R, at 1 as is standard in the literature.[15]

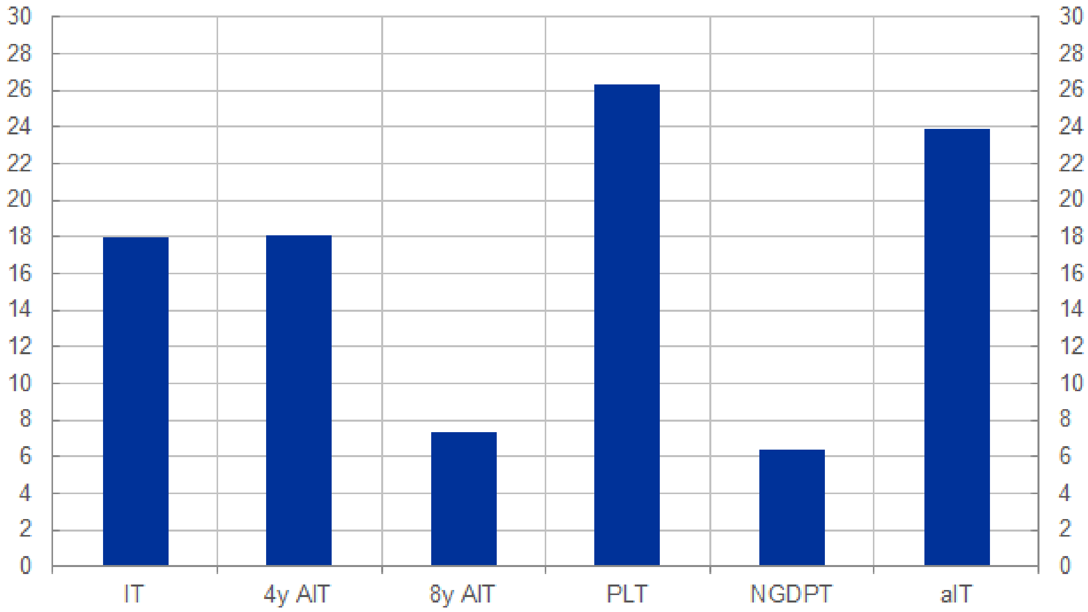
Figure 6 shows that NGDPT performs best, followed by 8-year AIT. Even though PLT and aIT improved upon IT in terms of bias reduction, the increased volatility weighs on their desirability in terms of welfare losses. As a caveat, all makeup strategies rely heavily on the expectations channel whereby agents fully anticipate that inflation undershooting will be followed by overshooting. In Section 8 we document the implications of varying the strength of the expectations channel.

7 Optimized simple rules

While in the previous section we have assessed the performance of simple policy rules calibrated as in Bernanke, Kiley, and Roberts (2019), in this section we choose the parameter values of the policy rules optimally following the approach of Levin, Wieland,

[15]See Kiley and Roberts (2017) for example.

Figure 6: Welfare losses: comparison across alternative policy strategies



Note: *Welfare is based on the results in Table 7. The period loss function is* $L = (\pi_t^4 - \pi^*)^2 + \omega_y(y_t - y^*)^2 + \omega_R(\Delta R_t)^2$, *with* $\omega_y = 0.25$, *and* $\omega_R = 1$.

and Williams (1999), Levin, Wieland, and Williams (2003) and Williams (2003) among others.[16]

The central bank's period loss takes the same form as in the exercise above. We focus on the policy rules describing average inflation targeting (AIT8) and price level targeting (PLT) because in the previous section we have found that they are among the best and worst performing policy strategies, respectively, making them prime candidates to explore the potential of optimized rules.[17] We analyse also IT as it acts as a benchmark strategy.

For each policy strategy, the functional form of the policy rule is the same as the one considered in the previous sections, but we choose optimally the magnitude of some of the parameters. Specifically, we consider two cases. In the first case we compute the optimal value of the response to the inflation (price) gap — namely, the gap between inflation and the inflation objective under IT, the gap between average inflation and the inflation objective under AIT8, and the gap between the price level and the deterministic price trend under PLT. In the second case we choose optimally for each policy rule also the value of the response to the lagged interest rate.

[16] In contrast to this early work on optimal simple rules, we impose the lower bound.
[17] We do not consider NGDPT here because such a strategy seems to apply more naturally to a dual-mandate central bank than to a central bank with a primary objective as the ECB.

The analysis is based on stochastic simulations using the same sequences of shocks we have used in the previous sections. In the simulations it is assumed that the inflation target is 2%, $r^* = 0.5\%$ and the ELB is -0.5%.

The findings are presented in Table 1. The results for the baseline parameterization employed in the previous sections is shown in the columns labelled 'Baseline', while results for the optimally-computed policy response are displayed in the columns labelled 'Optimal'. Two results stand out. First, in the case in which we choose optimally the response to only one parameter (inflation gap in IT, average inflation gap in AIT8 and price level gap in PLT), under AIT8 and PLT there is hardly any improvement in the loss compared to the baseline parametrization employed in the previous section. On the contrary, under IT there is a very large improvement compared to the baseline parameterization of the IT rule. Evidently, under AIT8 and PLT the optimal response coefficients are close to the values used in the baseline parameterization. Instead, under IT the optimal response to inflation is much stronger than in the baseline parameterization.[18] Both in the baseline parameterization and the optimization of the repose to the inflation gap, AIT8 is the best performing strategy.

Table 1: Optimal simple rules under alternative policy strategies and their properties

	Baseline			Optimal					
	IT	AIT8	PLT	IT $\alpha_{IT}^{opt} = 5.0$	AIT8 $\alpha_{AIT}^{opt} = 5.9$	PLT $\alpha_{PLT}^{opt} = 1.4$	IT $\alpha_{IT}^{opt} = 5.4$ $\rho^{opt} = 0.95$	AIT8 $\alpha_{AIT}^{opt} = 6.2$ $\rho^{opt} = 0.9$	PLT $\alpha_{PLT}^{opt} = 1.3$ $\rho^{opt} = 0.8$
LB frequency	18.02	14.27	13.34	21.63	14.05	13.72	12.96	11.36	13.20
LB duration	22.53	20.21	19.30	23.47	20.04	19.71	18.73	18.90	19.11
Mean inflation	1.74	1.97	1.99	1.81	1.97	1.99	1.99	1.98	2.00
Mean ygap	-0.74	-0.21	-0.17	-0.58	-0.21	-0.17	-0.18	-0.15	-0.16
Mean rate	2.87	2.63	2.64	4.36	2.63	2.64	2.63	2.60	2.64
RMSD inflation	3.05	1.39	3.48	1.97	1.43	3.45	1.37	1.38	1.39
RMSD ygap	5.84	4.60	7.49	4.40	4.53	7.55	4.79	4.56	4.39
RMS rate changes	0.41	0.34	0.33	0.58	0.22	0.33	0.33	0.27	0.32
Loss	18.02	7.35	26.29	9.04	7.30	26.22	7.73	7.18	6.84

Note: *RMSD is the root mean squared deviations of inflation and the output gap from their targets. RMS is the root mean squared changes in the policy rate. The inflation target is set at 2%, r^* at 0.5% and the ELB at -0.5%.*

Second, by optimally choosing also the interest-rate smoothing coefficient, we find that there is an improvement across all policy strategies but especially under PLT. Under IT the improvement is achieved via a stronger inflation response compared to the baseline and stronger interest rate smoothing compared to the baseline. Under AIT8 (PLT) the optimal response to the average inflation (price level) gap is similar to the case in which we optimize only over this term while the optimal interest-rate smoothing coefficient is larger under AIT8 and lower under PLT compared to the baseline parameterization. The

[18] The strong inflation response in the optimised simple rule is discussed, for instance, in Levin, Wieland, and Williams (1999), Levin, Wieland, and Williams (2003), and Schmitt-Grohe and Uribe (2007) in a setting that does not consider the ELB.

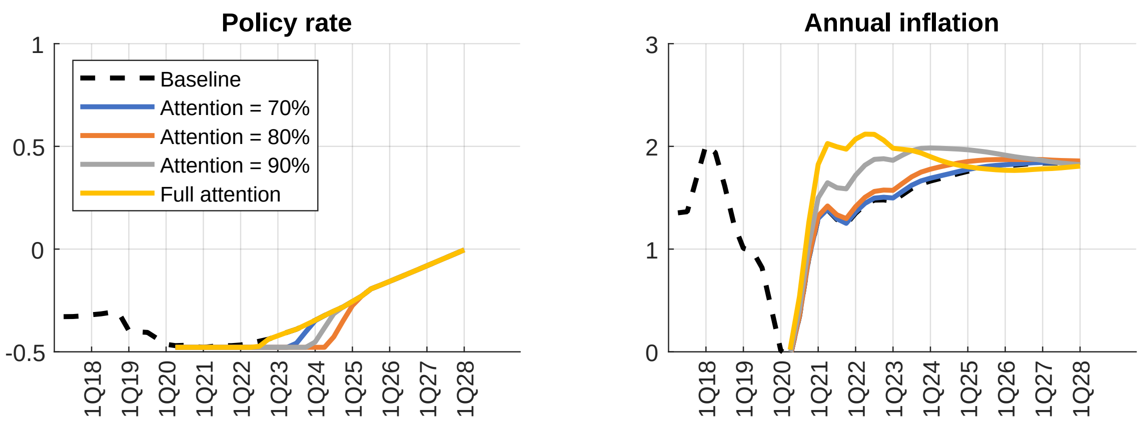
most dramatic improvement in terms of losses is found for PLT that now emerges as the best performing strategy. Overall, the main finding is that all strategies perform rather well in terms of biases and volatility and the differences in their associated loss become very small.

8 Optimal policy and expectations channel

Having analysed in the previous section optimal simple instrument rules, in this section we turn to fully optimal monetary policy. We take the perspective of standing in mid-2020—a time in which the ECB was undertaking the review of its monetary policy strategy—and inflation was well below target and the interest rate stood at -0.5%. We compute optimal monetary policy and assess the sensitivity of the benefits of makeup strategies to varying the strength of the expectations channel.

We assume that we stand in 2020Q2 and the "baseline projections" for the euro area are the ones provided in the June 2020 Broad Macroeconomic Projection Exercise (BMPE) conducted by Eurosystem staff, extended as follows. The June 2020 BMPE covers the horizon only up to end-2023, hence we extent it using survey information from Consensus Economics for inflation and market-based forward-rates for the short-term interest rate, and we condition on them to generate the path of the other variables. The baseline projections are depicted with the dashed line in Figure 7. We make three observations. First, at the beginning of the projection horizon, in 2020Q2, inflation is 0.2% and by then it had been below target (in annual terms) for seven consecutive years. Second, the baseline projection for inflation foresees a rise towards the 2% target very slowly, still falling short of the target in 2026. Third, the baseline path for the interest rate is very shallow, remaining at -0.5% until mid-2021 and then rising by only 40 basis points by the end of 2026.

Figure 7: Optimal policy with alternative assumptions for private-sector attention



Note: *Optimal policy based on the loss function in Equation (17). Results in percentage points. The simulations are conducted around the extended June 2020 BMPE baseline.*

Given these baseline projections, we compute the interest rate path that would minimise the loss function[19]

$$L_0 = \sum_{t=0}^{\infty} \beta^t \left[(\bar{\pi}_t^{(4)} - \pi^*)^2 + \omega_y (y_t - y^*)^2 + \omega_{dr} (\Delta R_t)^2 \right] \tag{17}$$

As in the previous section, we set $\omega_y = 0.25$, $\omega_{dr} = 1$, and the ELB at -0.5%. Optimal policy is derived under commitment. We assume that the central bank abstains from using asset purchases.

The yellow line in Figure 7 represents the optimal interest rate path.[20] It calls for keeping the interest rate at the ELB for longer, one additional year compared to the baseline. This leads to an inflation overshooting in the future, which in turn lowers the real interest rate and provides an immediate boost to inflation.[21] As a result, inflation reaches the 2% target already by 2021Q1, several years earlier than in the baseline projections. It is worth noting that this can be achieved with an overshooting of inflation that is very small and short-lived.

The strong and fast inflation response to the expectations of a lower-for-longer monetary policy suggests that the expectations channel is powerful in the model. To quantify the relevance of the expectations channel we vary the extent to which agents internalise the central bank's promise to deliver future accommodation, using the approach of de Groot and Mazelis (2020). Specifically, we assume that a constant fraction of agents are inattentive to central bank announcements about the future course of policy.[22] The benchmark case is a situation in which all agents are attentive, and this corresponds to the yellow line in Figure 7.

Figure 7 displays the results for different shares of agents' attentiveness. We make three observations. First, even small deviations from the benchmark case of full attentiveness affect the outcomes significantly. For instance, if the share of attentiveness drops to 90% (grey line in Figure 7), the lift-off date is delayed by more than one year compared to the

[19] Svensson (2020) refers to this approach of computing optimal policy as forecast targeting whereby a policy rate path is chosen so that the forecasts of target variables (e.g. inflation and economic activity) "look good", meaning that they minimise the loss function. Differently from optimized simple rules, this approach has the advantage of delivering fully optimal (but thus more complex) policy while retaining transparency and being easy to communicate. We let $t = 0$ denote the quarter in which the central bank chooses the optimal path for the policy instrument, defined as the path which minimizes the expected value of a specified loss function at quarter 0.

[20] The simulations are conducted with the impulse response function-based approach described in de Groot, Mazelis, Motto, and Ristiniemi (2021a) to construct couterfactual policy scenarios.

[21] For the history dependence of optimal policy in the presence of the lower bound, see Eggertsson and Woodford (2003), Adam and Billi (2006) and Nakov (2008).

[22] We do not model a situation in which there is a switch to a new policy strategy and agents have to learn the new strategy, e.g. via Bayesian updating. We assume that the strategy has been in place for some time and yet a fraction of agents remains inattentive.

case of full attentiveness. In turn, inflation reaches its 2% target two years later than in the case of full attentiveness.

Second, the impact of a declining share of attentive agents is non-monotonic.[23] Specifically, lowering the share of attentiveness leads to optimally postpone the lift-off date, but up to a critical value beyond which lift-off is brought forward again. For instance, if the share of attentive agents is 80% (orange line in Figure 7), lift-off is postponed compared to the case in which the share is 90%. Importantly, although lift-off is postponed, the inflation response is smaller and more delayed compared to the case of 90% attentiveness. If the share of attentiveness drops to 70% (red line in Figure 7) we have a reversal, with lift-off occurring at an earlier date than in the case in which attentiveness is 80%. Notably, with 70% attentiveness, inflation is not much affected by the anticipation of future accommodation. The earlier lift-off when attentiveness drops below a critical value is explained by the fact that in such circumstances policy accommodation in the distant future does little to close the currently prevailing negative inflation gap, which means that it brings little benefit to communicate a longer stay at the ELB already now. However, given the assumed loss function penalizing deviations of inflation from its target, when the future comes and the central bank has to deliver the additional policy accommodation that was promised in the past, it will be very costly. While it is always the case that optimal policy under commitment is time inconsistent, ex ante the cost associated with a future inflation overshooting is worth to be paid only if the additional future accommodation helps to close the negative inflation gap currently prevailing. But this is not the case if the share of attentiveness declines below a critical value.

Third, the effects of varying the share of attentive agents depend on the length of the ELB episode and the steepness of the interest rate path after lift-off as embedded in the baseline projections. The reason is that at the ELB the central bank can provide additional policy accommodation only by promising to postpone lift-off or to hike rates afterwards in a more gradual manner — we are assuming here that the central bank does not employ large-scale asset purchases. However, if the baseline projections embed a lift-off date far out in the future and subsequently the interest rate is foreseen to increase very gradually, additional policy accommodation can only be provided by promising lower interest rates in the very distant future — only at those horizons there is policy space available. But unless there is a high degree of attentiveness, the private sector becomes insensitive to policy actions that will take place in the very distant future. de Groot, Mazelis, Motto, and Ristiniemi (2021b) estimate the share of attentiveness to lie within the range of 70-81%.[24] Figure

[23]This non-monotonic behaviour was first uncovered in Nakata, Ogaki, Schmidt, and Yoo (2019) in a 3-equation New-Keynesian model using a different mechanism for dampening of FG effects in which agents discount future conditions more strongly.

[24]de Groot, Mazelis, Motto, and Ristiniemi (2021b) estimate the share of attentiveness together with the other parameters of the DSGE model. They show that using the estimated share of attentiveness their

7 (blue and orange lines) shows that such a share of attentiveness would imply that the benefits in terms of inflation stabilization that can be achieved by keeping the interest rate lower-for-longer as called for by makeup strategies are very modest. At the same time, it would still be optimal to delay lift-off by about one year compared to what is embedded in the baseline projections.

We conclude this section by analyzing Svensson's (2020) proposal of representing average-inflation targeting (price-level targeting) by means of a central bank loss function in which the deviation of the period-by-period inflation rate from its target is replaced by the gap between the moving average of inflation (the price level) and the inflation target (the deterministic price trend):[25]

$$\text{AIT:} \qquad L_0 = \sum_{t=0}^{\infty} \beta^t \left[(\bar{\pi}_t^{(8T)} - \pi^*)^2 + \omega_y (y_t^{gap})^2 + \omega_{dr} (\Delta R_t)^2 \right] \tag{18}$$

$$\text{PLT:} \qquad L_0 = \sum_{t=0}^{\infty} \beta^t \left[(p_t - p_t^*)^2 + \omega_y (y_t^{gap})^2 + \omega_{dr} (\Delta R_t)^2 \right] \tag{19}$$

The results are presented in Figure 8. First, optimal policy calls for offsetting the large average inflation gap (and the even larger price level gap) accumulated by the time in which we carry out our optimization exercise in 2020Q2. This requires a large inflation overshooting, as shown by the yellow line representing optimal policy assuming agents are fully attentive. Second, a lower degree of attentiveness leads to postpone lift-off,[26] and the impact on inflation becomes smaller and more delayed compared to full attention.

These results further exemplify that the benefits of makeup approaches depend on the strength of the expectations channel. For values of attentiveness consistent with empirical estimates, the benefits of makeup strategies tend to be small as shown by the blue and orange lines.

9 Conclusion

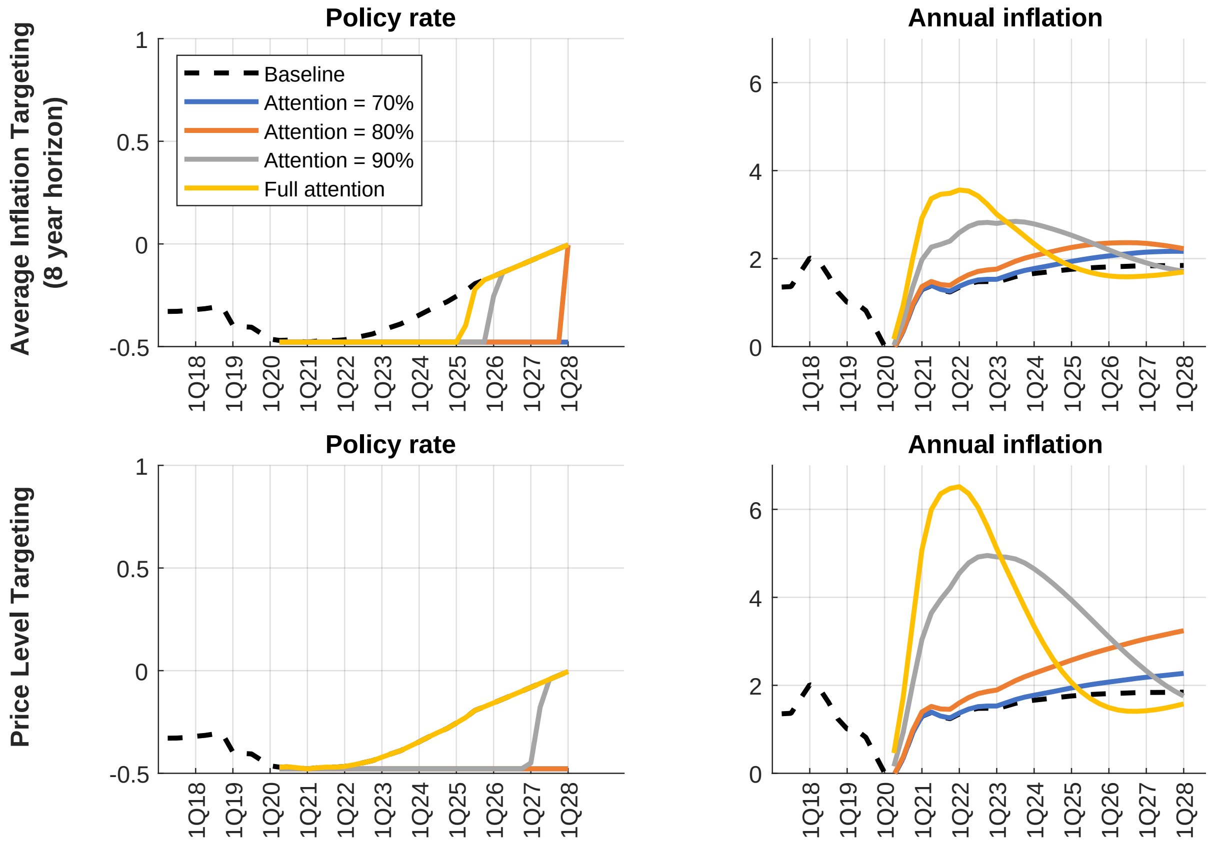
We estimate a model on euro area data and study the stabilization properties of alternative policy strategies in the presence of the lower bound and a low equilibrium real rate. If

model does not exhibit the forward guidance puzzle described in Del Negro, Giannoni, and Patterson (2015). Their estimated share of attentiveness implies that agents do not internalise central bank's promises about future policy rates beyond 4-5 years out into the future.

[25] Selecting the appropriate relative weight on output stabilization across loss functions representing alternative policy strategies is not straightforward (see Vestin, 2006, Svensson, 2020, and Budianto et al., 2020). For simplicity we use the same weight across specifications of the loss function, with $\omega_y = 0.25$.

[26] This is depicted in all cases except for PLT under full attention. In this scenario, instead of remaining at the ELB for longer, the optimal policymaker employs the power of the FG puzzle by reducing the policy rate by a small amount far in the future (not shown in the chart), which is fully anticipated by forward-looking agents and leads to the large inflation overshoot seen in the near-term.

Figure 8: Optimal policy under Average Inflation Targeting and Price Level Targeting with alternative assumptions for private-sector attention



Note: *Top panels: optimal policy based on loss function in Equation (18). Bottom panels: optimal policy based on loss function in Equation (19). Results in percentage points. The simulations are conducted around the extended June 2020 Eurosystem staff baseline.*

strategies are represented in terms of simple feedback rules as typically calibrated in the literature, we find that makeup strategies perform much better than inflation targeting, and within makeup strategies we find a clear ranking.

However, we find that differences across strategies become small if we optimize the response coefficients of the rules. Future research should assess the robustness of those rules across a variety of models featuring a low equilibrium real rate and an occasionally-binding lower bound constraint, given that optimized rules may tend to be model specific.

We show that addressing the excess sensitivity of inflation to interest rate expectations (the forward guidance puzzle) has implications for lower-for-longer policies such as makeup strategies. Assuming a degree of agents' attention to central bank's promises consistent with what can be found in the data implies that makeup strategies lose most of their traction. A systematic comparison of the implications of alternative expectations formation processes would be desirable.

We find that non-standard measures would not be sufficient in themselves to offset the destabilizing effects of the lower bound. We leave to future research to assess the robustness of this finding across alternative modelling choices of the channels of non-standard measures.

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Appendix

A The model

A.1 Model equations

With both a unit-root labour-augmenting technology shock, Z_t, and a stationary technology shock, ε_t^{α}, the production function of the intermediate goods producers is:

$$Y_t = \varepsilon_t^a (K_t^s(i))^{\alpha} (Z_t L_t(i))^{1-\alpha} - Z_t \Phi \tag{20}$$

with technological progress growing at the rate: $ln(Z_t/Z_{t-1}) = g_{z,t} = \rho^{g_z} g_{z,t-1} + \eta_t^{g_z}$.

All real variables in the model are detrended by the stochastic trend Z_t to ensure that the variables follow a balanced growth path:

$y_t = Y_t/Z_t, \quad c_t = C_t/Z_t, \quad i_t = I_t/Z_t, \quad \bar{k}_t = \bar{K}_t/Z_t, \quad \tilde{p}_t = \tilde{P}_t/P_t, \quad \tilde{\omega}_t = \tilde{W}_t/W_t,$
$q_t^k = Q_t^k \quad k_t = K_t/Z_t, \quad \omega_t = W_t/(P_t Z_t), \quad r_t^k = R_t^k/P_t, \quad \xi_t = \Xi_t Z_t^{\sigma_c}$

The production function of the intermediate goods producers becomes:

$$y_t Z_t = \varepsilon_t^a (k_t^s(i) Z_t)^{\alpha} (Z_t L_t(i))^{1-\alpha} - Z_t \Phi \tag{21}$$

Dividing throughout by Z_t:

$$y_t = \varepsilon_t^a (k_t^s(i))^{\alpha} (L_t(i))^{1-\alpha} - \Phi \tag{22}$$

The log-linearised model equations, where the real variables are detrended, are shown below.

Resource constraint:

$$\hat{y}_t = \hat{g}_t + c_y \hat{c}_t + i_y \hat{i}_t + z_y \hat{u}_t \tag{23}$$

Consumption Euler equation:

$$\begin{aligned}\hat{c}_t = {} & \frac{1}{1+he^{-g_z^*}} E_t[\hat{c}_{t+1}] + \frac{he^{-g_z^*}}{1+he^{-g_z^*}} \hat{c}_{t-1} - \frac{(1-he^{-g_z^*})}{\sigma_c(1+he_{-g_z^*})} R_t^{gap} + \hat{\hat{b}} \\ & - \frac{1}{1+he^{-g_z^*}} (he^{-\hat{g}_z^*} g_{z,t} - E_t \hat{g}_{z,t+1}) \\ & + \frac{(\sigma_c - 1)}{\sigma_c(1+he^{-g_z^*})} \frac{\omega^{*h} L^*}{c^*} (\hat{L}_t - E_t[\hat{L}_{t+1})]\end{aligned} \tag{24}$$

Investment Euler equation:

$$\hat{i}_t = \frac{1}{S''e^{2g_z^*}(1+\beta e^{(1-\sigma_c)g_z^*})}\hat{q}_t^k + \frac{1}{1+\beta e^{(1-\sigma_c)g_z^*}}(\hat{i}_{t-1} - \hat{g}_{z,t}) + \frac{\beta e^{(1-\sigma_c)g_z^*}}{1+\beta e^{(1-\sigma_c)g_z^*}}E_t[\hat{i}_{t+1} + \hat{g}_{z,t+1}] + \mu_t \tag{25}$$

Arbitrage equation value of capital:

$$\hat{q}_t^k = -R_t^{gap} + \frac{1}{\frac{1-he^{-g_z^*}}{\sigma_c(1+he^{-g_z^*})}}\hat{\bar{b}}_t + \frac{r^{*k}}{r^{*k}+(1-\delta)}E_t[r_{t+1}^k] + \frac{(1-\delta)}{r^{*k}+(1-\delta)}E_t q_{t+1}^k \tag{26}$$

Aggregate production function:

$$\hat{y}_t = \Phi(\varepsilon_t^a + \alpha\hat{k}_t + (1-\alpha)\hat{L}_t) \tag{27}$$

Definition of capital services:

$$ln(k_t) - ln(k^*) = \hat{k}_t = \hat{u}_t - \hat{g}_{z,t} + \hat{\bar{k}}_{t-1} \tag{28}$$

First order condition, capacity utilisation:

$$u_t = \frac{1-\psi}{}\hat{r}_t^k \tag{29}$$

Law of motion of capital:

$$\hat{\bar{k}}_t = (1 - \frac{i^*}{\bar{k}^*})(\hat{\bar{k}}_{t-1} - \hat{g}_{z,t}) + \frac{i^*}{\bar{k}^*}\hat{i}_t + \frac{i^*}{\bar{k}^*}S''e^{2g_z^*}(1+\beta e^{(1-\sigma_c)g_z^*})\hat{\mu}_t \tag{30}$$

First order condition, labour:

$$\hat{mc}_t = (1-\alpha)\hat{\omega}_t + \alpha\hat{r}_t^k - \varepsilon_t^a \tag{31}$$

Price Phillips curve:

$$\begin{aligned}\hat{\pi}_t = &\left(\frac{1}{1+\iota_p\bar{\beta}e^{g_z^*}}\right)(\bar{\beta}e^{g_z^*}E_t(\hat{\pi}_{t+1}) + \iota_p\hat{\pi}_{t-1} + (1-\iota_p)\hat{\bar{\pi}}_t - \bar{\beta}e^{g_z^*}(1-\iota_p)E_t[\hat{\bar{\pi}}_{t+1}] \\ &+ \frac{1}{((\phi_p-1)\varepsilon_p+1)} \quad \frac{(1-\zeta_p)(1-\zeta_p\bar{\beta}e^{g_z^*})}{\zeta_p}\Bigg)\hat{mc}_t) + \varepsilon_{p,t}\end{aligned} \tag{32}$$

Firm first order condition, capital:

$$\hat{r}_t^k = \hat{\omega}_t + \hat{L}_t - \hat{k}_t \tag{33}$$

Wage Phillips curve:

$$\begin{aligned}\hat{\omega}_t = & \frac{1}{1+\bar{\beta}e^{g_z^*}}\Big) (\hat{\omega}_{t-1} - \hat{g}_{z,t} + \bar{\beta}e^{g_z^*}(E_t[\hat{\omega}_{t+1}] + \hat{g}_{z,t+1} + E_t[\hat{\pi}_{t+1}]) - (1+\bar{\beta}e^{g_z^*}\iota_\omega)\hat{\pi}_t + \iota_\omega \hat{\pi}_{t-1} \\ & + (1-\iota_\omega)\hat{\bar{\pi}}_t - \bar{\beta}e^{g_z^*}(1-\iota_\omega)E_t[\hat{\bar{\pi}}_{t+1}] \\ & + \frac{(1-\zeta_\omega\bar{\beta}e^{g_z^*})(1-\zeta_\omega)}{\zeta_\omega((\phi_\omega - 1)\varepsilon_\omega + 1)}\left[-\hat{\omega}_t + \sigma_l \hat{L}_t + \frac{1}{1-he^{-g_z^*}}\hat{c}_t - he^{-g_z^*}\hat{c}_{t-1} + he^{-g_z^*}\hat{g}_{z,t}\right] + \varepsilon^\omega_{\omega,t}\end{aligned} \tag{34}$$

A.2 Shock processes:

$$\varepsilon_t^a = \rho^a \varepsilon_{t-1}^a + \eta_t^a \tag{35}$$
$$\varepsilon_t^{gz} = \rho^{gz} + \varepsilon_{t-1}^{gz} + \eta_t^{gz} \tag{36}$$
$$\varepsilon_t^b = \rho^b \varepsilon_{t-1}^b + \eta_t^b \tag{37}$$
$$\varepsilon_t^g = \rho^g \varepsilon_{t-1}^g + \eta_t^g \tag{38}$$
$$\varepsilon_t^i = \rho^i + \varepsilon_{t-1}^i + \eta_t^i \tag{39}$$
$$\varepsilon_t^m = \rho^m \varepsilon_{t-1}^m + \eta_t^m \tag{40}$$
$$\varepsilon_t^p = \rho \varepsilon_{t-1}^p + \eta_t^p + \mu_t^p \eta_{t-1}^p \tag{41}$$
$$\varepsilon_t^\omega = \rho \varepsilon_{t-1}^\omega + \eta_t^\omega + \mu_t^\omega \eta_{t-1}^\omega \tag{42}$$
$$\varepsilon_t^n = \rho^n \varepsilon_{t-1}^n + \nu_t^n \tag{43}$$

A.3 Data

We use eight quarterly euro area variables: the log difference of real GDP, real consumption, real investment, real wages, and the harmonised index of consumer prices; the log of hours worked; the short-term nominal interest rate; the output gap. We treat the output gap, y_t, as observable because we want it to be consistent with policymakers' view. We rely on the OECD's estimate of the output gap. For the interest rate we use the shadow rate constructed in De Rezende and Ristiniemi (2023). The measurement equations are shown below. Given uncertainty in measuring potential output, we have included a measurement error in the observation equation for the output gap.

$$
\begin{aligned}
dc_t^{obs} &= c_t - c_{t-1} + g_{z,t} + g_z^* \\
di_t^{obs} &= i_t - i_{t-1} + g_{z,t} + g_z^* \\
dy_t^{obs} &= y_t - y_{t-1} + g_{z,t} + g_z^* \\
dw_t^{obs} &= w_t - w_{t-1} + g_{z,t} + g_z^* \\
y_t^{obs} &= y_t + \sigma^y \varepsilon_t^y \\
pi_t^{obs} &= \pi_t + \bar{\pi} \\
l_t^{obs} &= l_t + \bar{l} \\
R_t^{obs} &= R_t + R^*
\end{aligned}
$$

B Calibration

Parameter		Calibration
Steady state inflation rate (quarterly)	$\bar{\pi}$	0.475
Capital depreciation rate	δ	0.025
Gross mark-up on wages	ϕ_w	1.3
Share of government spending in output	$\frac{\bar{g}}{\bar{y}}$	0.18
Curvature of Kimball aggregator for wages	ε_w	10
Curvature of Kimball aggregator for prices	ε_p	10
Discount rate	$100(\beta^{-1} - 1)$	0.16
Measurement error of standard deviation of the output gap	σ^y	0.285
QE on shadow rate	ξ^{qe}	0.02
QE autoregressive parameter, t-1	ρ^{qe1}	1.5
QE autoregressive parameter, t-2	ρ^{qe2}	-0.54
QE parameter on inflation	θ^{qe}	-2.5
QE parameter on quarterly Taylor interest rate gap	τ^{qe}	1.25

Table 2: Calibrated parameters

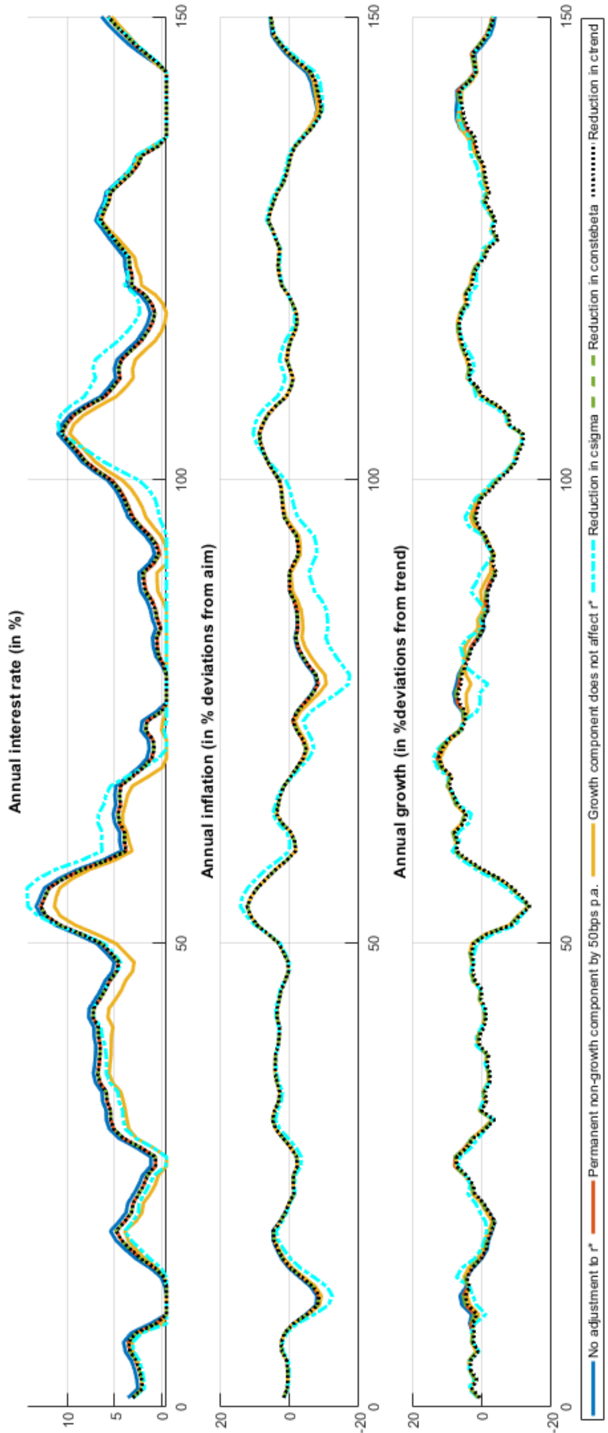
C Estimation

	Variable	Distribution	Prior Mean	Prior Std	Posterior Mode
Standard errors:					
Technology shock	σ_a	Inv. Gamma	0.1	2	0.25
Risk premium shock	σ_b	Inv. Gamma	0.1	2	0.05
Government spending shock	σ_g	Inv. Gamma	0.1	2	0.32
Investment shock	σ_i	Inv. Gamma	0.1	2	0.95
Monetary policy shock	σ_m	Inv. Gamma	0.1	2	0.13
Price mark-up shock	σ_p	Inv. Gamma	0.1	2	0.03
Wage mark-up shock	σ_w	Inv. Gamma	0.1	2	0.13
Permanent technology shock	σ_{gz}	Inv. Gamma	0.1	2	0.16
Persistence:					
Technology shock	ρ^a	Beta	0.5	0.2	0.91
Risk premium shock	ρ^b	Beta	0.8	0.1	0.90
Government spending shock	ρ^g	Beta	0.5	0.2	0.97
Investment shock	ρ^i	Beta	0.5	0.2	0.08
Monetary policy shock	ρ^m	Beta	0.5	0.2	0.65
Price mark-up shock	ρ^p	Beta	0.5	0.2	0.85
Wage mark-up shock	ρ^ω	Beta	0.5	0.2	0.72
Permanent technology shock	ρ^{gz}	Beta	0.5	0.05	0.52
Other parameters:					
Calvo wages	ξ_w	Beta	0.75	0.1	0.84
Calvo prices	ξ_p	Beta	0.75	0.02	0.77
Indexation wages	ι_w	Beta	0.5	0.2	0.33
Indexation prices	ι_p	Beta	0.5	0.2	0.75
Coeff. MA term price mark-up	μ_p	Beta	0.5	0.2	0.25
Coeff. MA term wage mark-up	μ_w	Beta	0.5	0.2	0.91
Risk aversion	σ_c	Gaussian	1.5	0.1	1.21
Frisch elasticity	σ_l	Gaussian	2.5	0.75	2.88
Degree of habit formation	λ	Beta	0.7	0.1	0.79
Investment adjustment cost	φ	Gaussian	6	1.5	7.00
Fixed cost share	ϕ_p	Gaussian	1.25	0.125	1.36
Capacity utilisation cost		Beta	0.5	0.1	0.55
Capital share	α	Gaussian	0.3	0.05	0.11
Steady state net growth	$100(g_z^* - 1)$	Gaussian	0.3	0.02	0.28
Steady state hours	$\bar{l}$	Gaussian	0	2	0.83
Coeff. Potential growth on R^*	θ^{rn}	Beta	0.15	0.1	0.08
Feedback tech. on ex. spending	ρ_{ga}	Gaussian	0.5	0.2	0.69
Policy rule inflation	r_π	Gaussian	1.85	0.25	2.12
Policy rule output gap	r_y	Gaussian	0.1	0.2	0.30
Policy rule persistence	ρ^m	Beta	0.75	0.1	0.79

Table 4: Priors and posteriors

D Simulations

Figure 9: Comparison of methods to adjust the natural rate of interest



Note: *The simulations are conducted with DynareOBC (Holden, 2016). The same random shock series is applied to all different specifications.*

Table 5: ELB simulation results

Inflation aim pi*	Equilibrium real interest rate r* (p.a.)	Effective lower bound (p.a.)	Lower-bound incidence		Inflation (P.P., annual)		Output gap (%)		Growth (%, quarterly)		Interest rate (P.P., annual)	
			Frequency (%)	*Avg. duration (quarters)*	*Mean*	*Std*	*Mean*	*Std*	*Mean*	*Std*	*Mean*	*Std*
3%	1%	**0.00%**	10.63	16.5	2.9	2.16	-0.28	3.69	-0.01	2.56	4.17	2.81
		-0.50%	7.91	14.2	2.94	2.06	-0.18	3.39	0	2.4	4.11	2.87
2%	2%	**0.00%**	11.09	16.95	1.92	2.22	-0.29	3.8	0	2.65	4.15	2.83
		-0.50%	8.38	14.91	1.95	2.07	-0.2	3.4	0	2.47	4.09	2.89
	1%	**0.00%**	18.04	22.52	1.74	3.05	-0.75	5.81	0	3.7	3.37	2.7
		-0.50%	14.58	19.93	1.84	2.57	-0.49	4.7	-0.01	3.08	3.23	2.77
	0%	**0.00%**	23.84	26.54	1.55	4.15	-1.25	8.13	0.01	4.92	2.87	2.56
		-0.50%	21.11	24.52	1.64	3.44	-0.98	6.68	0	4.21	2.58	2.62
1%	1%	**0.00%**	28.1	30.11	0.45	4.41	-1.45	8.48	0.05	5.33	2.58	2.46
		-0.50%	26.13	28.23	0.52	3.85	-1.29	7.46	0	4.82	2.17	2.48

Note: *The statistics are based on 2000 simulations of 150 periods, excluding the first 50 periods as burn-in. We exclude runs where inflation goes below – 10%, as this substantially biases the results.*

Table 6: Asset purchase simulation results

Policy rules	**Lower-bound incidence**		**Inflation (annual)**		**Output gap (%)**	
	Frequency (%)	*Average duration (quarters)*	*Mean*	*Std*	*Mean*	*Std*
Inflation targeting rule	18.02	22.53	1.74	3.04	-0.74	5.79
Inflation targeting rule + QE-rule only at the ELB	19.01	23.41	1.88	2.11	-0.47	3.81
Inflation targeting rule + permanent QE-rule	10.91	16.88	1.99	1.08	-0.08	3.23
Inflation targeting rule + QE-rule only at the ELB, QE max 50% of long-term bonds	16.50	20.96	1.91	2.26	-0.36	4.00

Note: *The statistics are based on 2000 simulations of 150 periods, excluding the first 50 periods as burn-in. We exclude runs where inflation goes below –10%, as this substantially biases the results. The effective lower bound of the policy rate is set to -0.5%. The inflation target* π^* *is set to 2% and* $r^* = 0.5\%$.

Table 7: Make-up strategy simulation results

Policy rules		**Lower-bound incidence**		**Inflation (annual)**		**Output gap (%)**		**Welfare**
		Frequency (%)	*Average duration (quarters)*	*Mean*	*Std*	*Mean*	*Std*	*Loss*
Benchmark inflation targeting rule	**with ELB of -0.5%**	18.02	22.53	1.74	3.04	-0.74	5.79	18.02
	without ELB			2.02	1.77	0.00	2.50	4.89
4-year Average Inflation Targeting rule		16.28	23.01	1.80	2.85	-0.57	6.22	18.04
8-year Average Inflation Targeting rule		14.27	20.21	1.97	1.39	-0.21	4.60	7.35
Price Level Targeting		13.34	19.30	1.99	3.48	-0.17	7.49	26.29
Nominal GDP Targeting		17.20	22.01	2.00	1.44	-0.21	4.05	6.35
Asymmetric inflation rule, $\phi = 1$		19.65	24.03	1.58	4.81	-1.12	9.53	23.83

Note: *The statistics are based on 2000 simulations of 150 periods, excluding the first 50 periods as burn-in. We also exclude runs where inflation goes below –10 as this substantially biases the results. The effective lower bound of the policy rate is set to -0.5%. The inflation target π^* is set to 2% and $r^* = 0.5\%$. The Loss is computed using Equation (16).*

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