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Monetary Policy Rules and the Effective Lower Bound in the Euro Area

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Abstract

We analyze the economic performance of different monetary policy strategies, or rules, in a low interest rate environment, using simulations with a DSGE model which has been estimated for the euro area. We study how often the effective lower bound of interest rates (ELB) is likely to bind, and how much forgone monetary policy accommodation this entails. Macroeconomic outcomes are measured by the mean levels and the volatility of output (gaps), unemployment and inflation. We present three sets of results. First, the macroeconomic costs of the ELB are likely to grow in a non-linear manner if the monetary policy space (the difference between the normal, or average, level of nominal interest rates and the ELB) shrinks. Second, a point inflation target appears to outperform a target range. Third, the (relative) performance of low-for-long (L4L) monetary policy rules depends on the size of the monetary policy space. The L4L rules tend to perform well, if the monetary space is small, but if the space is larger these rules, while stabilizing inflation, may lead to more volatility in the real economy than flexible inflation targeting.

Keywords: monetary policy rules, effective lower bound, euro area

JEL codes: E31, E32, E52, E58

1. Introduction

In recent decades, natural interest rates have declined globally (see e.g. Holston et al. (2017)). At the same time central banks have adopted inflation targets of about 2 per cent. Together, these facts imply that nominal interest rates have become more likely to hit their effective lower bound (ELB).

One reason for pursuing low inflation is that before the financial crisis the incidence of the ELB was estimated to be negligible. This is clear, for example, from the studies that were used as a background material when the European Central Bank (ECB) evaluated its strategy in 2003. The background studies by Coenen (2003) and Klaeffling and López Pérez (2003) estimated that the probability of hitting the ELB, assuming equilibrium real rate and inflation target of 2 per cent, was between 0 and 17 per cent in the euro area. Issing (2003) summarized the existing literature concerning the likelihood of hitting the ELB as follows: "While results in this area are highly uncertain and depend on a number of specific assumptions, most available studies indicate that the likelihood decreases to very low levels when the objective of the central bank is set at an inflation rate above 1%".

More recent literature suggests that the probability of hitting the ELB is considerably higher than found earlier (e.g. Kiley and Roberts, 2017; Bernanke, Kiley, and Roberts, 2019). One central reason for the high estimates are the lower estimates of equilibrium interest rate. According to the simulations by Kiley and Roberts (2017), the probability of ELB about doubles as the equilibrium nominal rate declines from 4 to 3 per cent. In addition, their results show that the adverse effects of the ELB are substantial if monetary policy follows traditional rule by Taylor (1993). Bernanke et al. (2019) provide some evidence that "low-for-long" (L4L) policies like flexible price-level targeting could mitigate these adverse effects.

In this paper we analyze the economic performance of different monetary policy strategies, or rules, in a low interest rate environment, using a DSGE model which has been estimated for the euro area. Our simulation results suggest that the incidence of the ELB can be quite high: for example, if the monetary policy space (the difference between the normal, or average, level of nominal interest rates and the ELB) is 3 percentage points, monetary policy is at the ELB almost 30% of the time. This number is in line with the recent studies by Kiley and Roberts (2017) and Bernanke et al. (2019) that consider the incidence in the USA. We also find that the ELB may entail significant macroeconomic costs, especially on the real side of the economy: output tends to be lower, and the unemployment rate higher. Furthermore the economic costs of the ELB grow in a non-linear manner when the monetary policy space shrinks. However, the results show that the costs depend on the chosen monetary policy strategy or rule.

These results are highly relevant for the ECB's ongoing strategy review. This paper, which is a part of a broader set of model based analyses conducted within the Eurosystem, contributes to the existing literature in multiple ways.

First, the paper revisits the question about the relevance of the ELB (e.g. Orphanides and Wieland, 1998; Reifschneider and Williams, 2000; Coenen, 2003; Klaeffling and López Pérez, 2003; Williams, 2009; Kiley and Roberts, 2017; Bernanke et al. 2019). A large part of the existing research is conducted applying either Federal Reserves's principal simulation model (FRB/US) or DSGE models estimated/calibrated for the US economy. Our work contributes to the ongoing efforts to study these issues in the euro area context. The results support the idea that the ELB is much more severe problem than previously thought.

Second, the paper contributes to the literature assessing different monetary policy strategies in a low-rate environment (e.g. Adam and Billi, 2006; Hebden and López-Salido, 2018; Bernanke et al. 2019). As a baseline we use an estimated policy rule that involves the central bank reacting to one-year-ahead forecasted inflation, to a measure of the output gap and to a measure of the (time varying) natural rate.[1] We also consider a number of low-for-low (L4L) strategies. These strategies include rules which involve the central bank reacting to a measure of past inflation, on top of inflation forecasts and to a measure of real activity. The L4L rules we consider also include temporary price level targeting, which is a threshold type rule suggested by Bernanke (2017). Our results suggest that while the L4L strategies keep the volatility of inflation low, they may have the downside of resulting in more volatility in the real economy. However, if the monetary policy space is (very) tight, and the ELB imposes stringent constraints on monetary policy, the L4L strategies tend to outperform the baseline monetary policy rule. Under these circumstances the L4L strategies result in similar outcomes as the baseline rule for the real economy, but more stable inflation. Instead, our results indicate that so called corridor strategies, where the central bank does not react, or reacts only weakly, to changes in inflation (expectations) within a certain corridor (e.g. 1.0 - 2.0%), tend to lead to poor economic outcomes. The question of defining (or operationalizing) price stability in terms of a target range for in-

[1] Among a large number of different alternative policy rules considered, this rule fits the data the best.

flation, instead of a point aim, has received attention in the on-going monetary policy review. This paper contributes to the efforts of assessing the economic consequences of adopting such a definition of price stability in a low interest rate environment.

Third, the paper also relates to the literature that analyzes how central banks actually react to macroeconomic developments (e.g. Paloviita et al. 2020). Our results suggest that the ECB's reaction function includes one-year-ahead expected inflation, output gap, gap accelerator (i.e. change in the output gap) and natural interest rate.

The rest of the paper is structured as follows. In Section 2 we briefly describe the model framework we use in the analysis, discuss our baseline monetary policy rule and the effective lower bound, and present the simulation setup. In Sections 3-5 we then analyze the different monetary policy rules and report the results from model simulations. Section 3 focuses on the macroeconomic effects of the ELB, under our estimated baseline monetary policy rule. In particular we demonstrate that the economic costs of the ELB grow in a non-linear manner when the monetary policy space shrinks. In Section 4 we analyze the macroeconomic implications of the target range definition of price stability (and the corridor type monetary policy rules) low interest rate environments where the ELB is likely to occasionally bind. In Section 5 we assess the performance of the "low-for-long" (L4L) rules. Finally Section 6 provides some concluding remarks.

2. Model framework and simulation setup

2.1. Model framework

We use a model framework that builds on the work by Smets and Wouters (2003, 2007), Gali, Smets and Wouters (2011) and Gertler and Karadi (2011). The starting point is the well-known Smets-Wouters (2003, 2007) model. This model features both sticky prices and sticky wages. These nominal rigidities are empirically realistic, and they are also important for the analysis of monetary policy. It also incorporates a number of other frictions and features, which improve its empirical fit, and hence make it more useful in policy analysis. These features include adjustment (or installation) costs in investments, variable capital utilization rate, habit persistence in consumption, and indexation of wages and prices to their previous values.

The Gali-Smets-Wouters (2011) model differs from the Smets-Wouters (2003,

2007) framework in that it involves an explicit treatment of unemployment. Including unemployment into the analysis is evidently important and useful: in particular it allows us to assess the economic costs of the ELB in terms of higher unemployment. Furthermore, having unemployment as an observed variable disciplines and informs the model-based estimates of the output gap.

Finally, to address financial frictions, we augment the Gali-Smets-Wouters (2011) framework with an explicit treatment of financial intermediation, modeled as in Gertler and Karadi (2011). In particular, the Gertler-Karadi model includes two interest rates: an interest rate on riskless and liquid assets (in the model households' deposits in banks) and an interest rate on assets which can be thought of as riskier and less liquid (in the model the yield on the funds the banks invest in non-financial firms); the spread between the interest rates is an observed variable in our framework.

Note that unlike in the simplest possible - or canonical - New Keynesian models, in our framework with multiple frictions (as well as shocks) the 'divine coincidence' does not hold. Hence, there is typically a trade-off between stabilizing inflation and the real side of the economy. Also note that the model is analyzed under the assumption of rational, or model-consistent, expectations. This assumption means that the economic agents fully understand the structure of the economy (and also believe that other actors understand it). The assumption also implies that the monetary policy rules in place are fully understood by the public, as well as credible.

2.2. Data

We estimate the model using the following euro area macro and labor market time series: real GDP, real private consumption, real investments, GDP deflator, nominal wage rate, unemployment rate, employment (as a share of working-age population) and short nominal interest rate (3 month Euribor). In addition, we use a measure of euro area banks spreads, which we have adopted from the recent empirical work by Gilchrist and Mojon (2017). These are the average spreads on the yield of euro area banking sector bonds relative to the yield on German federal government securities of matched maturities. In particular, this measure of spreads aims at capturing credit risk and liquidity premia, and at disentangling these from term premia.

The model includes as many shocks as there are observed variables. The 9 shocks include a TFP shock, an investment specific (technology) shock, a demand shock, a labor supply shock, a price mark-up shock, a wage mark-up shock, a risk shock (appetite for safe assets), a financial shock (tightness of financial conditions) and a monetary policy shock.

The model is estimated with Bayesian methods. The estimation period is 1999Q1:2016Q4. We use the subsample 1999Q1:2014Q2 to estimate the model parameters, and the entire sample to filter latent variables (such as the natural rate of interest) and shocks. The end of the parameter estimation subsample 2014Q2 is the time when the euro area hit the effective zero lower bound of interest rates.[2] As a robustness check we have also estimated the model parameters using the subsample 1999Q1:2007Q3, predating the financial crisis.

2.3. Baseline monetary policy rule

Following the work by Curdia et al. (2011, 2015) – who analyze US monetary policy – we have estimated the model with a large number of different monetary policy rules (Haavio, Juillard and Matheron 2020). Among these options we then choose the rule that appears to fit euro area data the best.

We consider Taylor rules, where the current (period t) policy rate depends on

a) the past (period t-1) policy rate

b) a measure of inflation

c) a measure of real activity

d) and possibly on a measure of the natural rate of interest.

We consider alternative inflation measures (current inflation vs. expected future inflation; quarterly inflation vs. annual inflation), alternative measures of real activity (model-based output gap, statistical output gaps based on the Hodrick-Prescott (HP) filter, GDP growth, no measure of real activity; measures of current real activity vs. expected future real activity). We consider rules both with and without the natural rate of interest. Our measure of the (time-varying) natural rate of interest is obtained as a part of the model estimation (it is the flex-price measure of the natural rate first suggested by Woodford (2003)) .

[2] We estimate a linearized model, but evidently the zero lower bound implies a non-linearity in the monetary policy rule. Then it is better to estimate the linear model using a subsample that excludes the zero lower bound period, and then let the ZLB deviations from the linear structure be captured shocks.

The estimated monetary policy rules are of the general form:

$$\begin{aligned} \textit{interest rate}_t &= \rho * \textit{interest rate}_{t-1} \\ &\quad + (1-\rho)\left[\beta_\pi * \textit{inflation} \; + \beta_y * \textit{real activity}\right. \\ &\quad \left. +\beta_{ac} * D_1 * \textit{gap accelerator} + D_2 * \textit{natural rate} \;\right] \\ &\quad + \textit{monetary policy shock} \end{aligned} \tag{1}$$

where ρ, β_π, β_y and β_{ac} are estimated coefficients, D_1 is a dummy variable which takes the value 1 if a gap accelerator (change in the output gap) is included in the monetary policy rule (and 0 otherwise), and D_2 is a dummy variable which takes the value 1 if the natural rate is included in the monetary policy rule (and 0 otherwise). Note that here all variables are deviations from their average (or steady steady state) values. Hence no intercept is needed in the monetary policy rules. Altogether, we have estimated 80 model variants with different monetary policy rules.

As the "baseline model", we choose the model variant with the best fit, or the highest marginal data density. The monetary policy rule with the best fit includes

- one-year-ahead expected future annual inflation,
- current model-based output gap,
- a gap accelerator
- and a (model-based) measure of the natural interest rate.

The coefficients of the baseline rule are given in Table 1.

Table 1. Parameters of the baseline rule

ρ	β_π	β_y	β_{ac}
0.87	2	0.5	0.6

2.4. Effective lower bound

We impose the effective lower bound (ELB) on the implied policy rate. For example, assuming that the baseline rule is applied, the interest rate in period t is given by the rule (1) if the rule-implied policy rate is above the ELB. If the lower bound constraint is binding,

$$\textit{interest rate}_t = ELB \tag{2}$$

The effective lower bound is taken into account using the OccBin toolbox of Gerrieri and Iacoviello (2015) which allows the analysis of piece-wise linear DSGE models, with occasionally binding constraints and multiple regimes. Notice that the OccBin approach rules out the possibility of the economy getting indefinitely stuck in a liquidity trap: when the economy is not buffeted by shocks, it eventually returns (by assumption) to the intended steady state.

2.5. Simulation setup

Our aim is to study the baseline monetary policy rule and a set of alternative rules in a low interest rate environment. The analysis is based on simulations conducted with the euro area DSGE model briefly described above. The length of each simulation is 10 000 periods, with shocks hitting the economy in every period. The shocks are normally distributed, with estimated standard deviations. At the beginning of a simulation the economy is assumed to be at the (intended) steady state (i.e. at the steady state where inflation is at its target level). After the 10000 periods with shocks, we let the simulation run for another 1000 periods without any new shocks; during this final phase the model returns to the (intended) steady state. We discard the results from the first 100 periods, as well as from the last 1000 (without shocks): hence our analysis is based on the simulation results from a sample of 9900 periods.

3. Baseline monetary policy rule and the ELB

3.1. Monetary policy space

In our first set of simulations we study how the ELB constrains monetary policy and affects macroeconomic outcomes if the central bank follows our estimated baseline monetary policy rule (1). In particular, we analyze how the incidence and the macroeconomic consequences of the ELB depend on the monetary policy space. The term "monetary policy space" refers to the difference between average (or normal) short turn interest rates and the ELB. For, example if the average short rate is 2.5% and the ELB is -50 basis points, the monetary policy space is 3 percentage points: in this case the nominal rate can fall 3 percentage points from its average (or normal) level before the ELB is reached. Also notice that the long-run average short rate should be equal to the sum of the long-run average natural rate of interest and the inflation target.

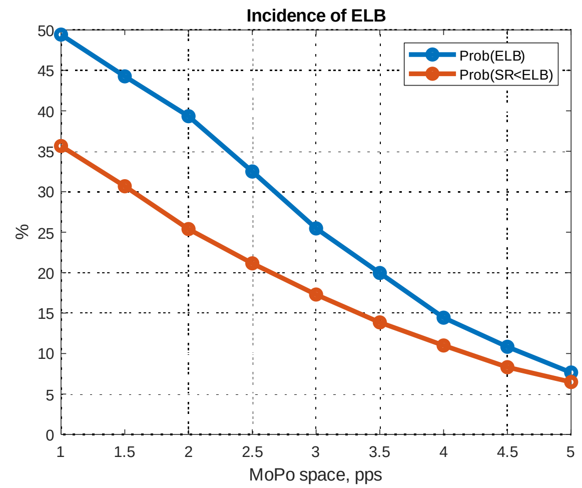

Figure 1: Monetary policy space and the incidence of ELB. Note: The shadow interest rate is the counterfactual interest rate which is not constrained by the ELB

3.2. Incidence of ELB

We begin our analysis by looking at the incidence of the ELB. When the monetary policy space is of the order of magnitude of 4 or 5 percentage points (or larger), the probability of being at the effective lower bound is relatively low (see the blue curve in Figure 1). According to our simulations the economy is at the ELB roughly 7% of the time if monetary policy space is 5 pps, and 14% of the time if the space is 4 pps. This corresponds perhaps to the (perceived) situation during the Great Moderation, and the results we get (assuming that the monetary policy space is 4 pps or wider) are of the same order of magnitude as many of the pre-crisis estimates of the probability of the ELB.

However, when the monetary policy space shrinks, the probability of being at the ELB grows. For example, if the monetary policy space is 3 percentage points, our simulations suggest that monetary policy is at the ELB 26% of the time (blue curve in Figure 1). This result is similar to the findings of Kiley and Roberts (2017) and Bernanke, Kiley and Roberts (2019), whose simulations suggest that the US economy could be at the ELB roughly 30% of the time (or even more often), when the monetary policy space is 3 percentage points. Recent studies, conducted in the context of the ongoing euro area monetary policy strategy review, suggest a roughly similar incidence of the ELB for the euro area, assuming that

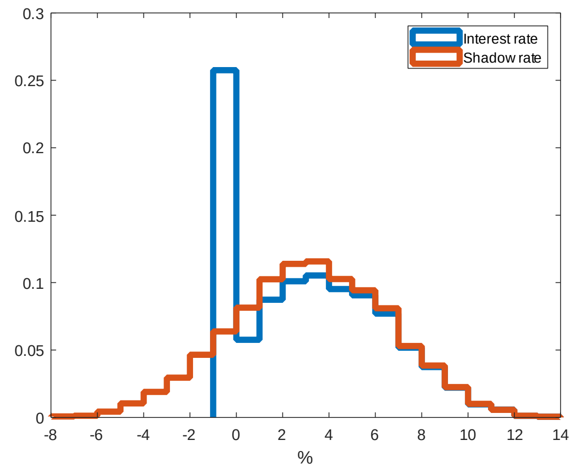

Figure 2: Distribution of the short interest rate and the shadow rate when the monetary policy space is 3 percentage points.

the monetary policy space is 3 percentage points.[3]

Moreover, the relationship between the width of the monetary policy space and the incidence of the ELB is somewhat non-linear (Figure 1). The reason is two-fold: First, if the average nominal interest rate falls (due to for example a lower natural rate), the interest rate implied by the baseline rule becomes negative (or lower the ELB) more often. The distribution of (shadow) interest rates implied by the baseline rule (and abstracting from the ELB) tends to be humpshaped (see the distribution of the shadow interest rate in Figure 2, marked in red): there is more mass around the "normal" or average values than in the tails. Hence, when the "normal" or average values of the interest rate fall (so that the distribution of the rule-implied rates shifts to the left), the probability mass of ruled-implied rates below the ELB grows in a non-linear manner. Since the interest rate cannot be below the ELB, also the probability of being at the ELB grows in a non-linear manner. This first effect is captured by the red curve in Figure 1.

Second, since the interest rate cannot fall below the ELB, negative output gaps tend to be larger and inflation lower after recessionary/disinflatory shocks. But these macroeconomic effects of the ELB feed back into monetary policy, so

[3]These simulations have been conducted with different euro area macro models, for the Eurosystem Monetary Policy Committee Workstream on Price Stability Objective. At the time of writing the results from this workstream have not yet been published.

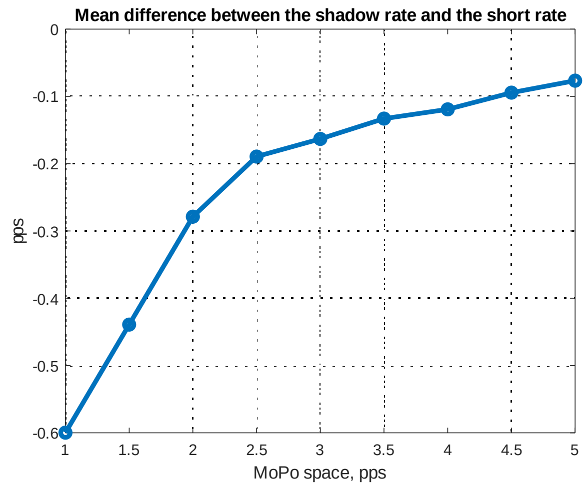

Figure 3: Mean difference between the shadow rate and the short interest rate over the whole simulation sample.

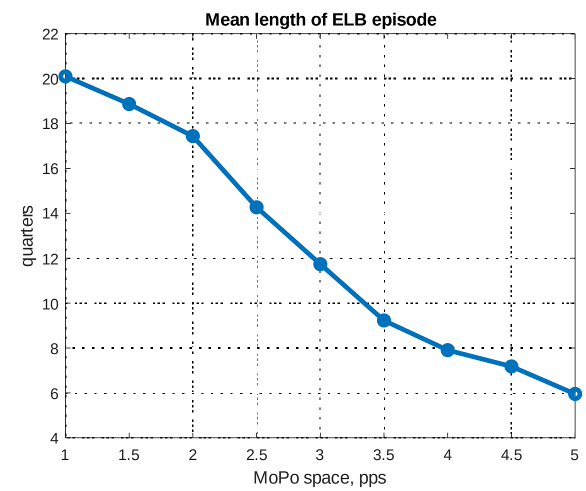

Figure 4: Average lenght of an ELB episode

it is even more likely that monetary policy is at the ELB. This second effect is captured by the difference between the blue curve (the probability of being at the ELB) and the red curve (the probability that the rule-implied (shadow) interest rate is below the ELB) in Figure 1.This second effect can be also seen in the probability distributions shown in Figure 2: the distribution of the actual interest rate, in blue, and the distribution of the shadow rate, in red, differ somewhat also in the hump and in the right tail.

Remember that the shadow rate is the interest rate that the central bank would set, following the monetary policy rule (1) if it were not constrained by the ELB. Then the (average) difference between the shadow rate and the actual interest rate, which is constrained by the ELB, can be interpreted as a measure of forgone monetary policy accommodation. This difference becomes more pronounced, when the monetary space gets tighter (Figure 3). Also the ELB episodes are the longer, on average, the tighter the monetary policy space (Figure 4).

Our analysis does not take into account unconventional monetary policy tools such as large scale asset purchases by the central bank. Some recent studies (e.g. Debortoli et al (2019)) suggest that such unconventional measures may have been a more or less perfect substitute to conventional monetary policy. If this is the case, the red curve in Figure 1 could perhaps be interpreted as the probability of conventional policy being constrained by the ELB, and unconventional policy tools being in place.

3.3. Macroeconomic consequences of ELB

Next we turn to the macroeconomic consequences of the ELB. We focus on three key macro variables: The output gap and the unemployment rate measure the real side of the macro economy. (Also note that in our model the model-consistent output gap and the unemployment rate are very closely related to each other, with (large) negative output gaps being typically associated with high unemployment rates.) On the nominal side, we analyze the annual inflation rate.

Above we saw that the ELB tends to bind more often, the ELB episodes tend to be longer and the foregone monetary policy accommodation tends to be more significant, when the monetary policy space shrinks. Not surprisingly, we find a similar relationship between the monetary policy space and the effects of the ELB on macro dynamics.

The ELB does not affect macro dynamics that much, when the monetary policy space is ample. However, the macroeconomic consequences of the ELB become

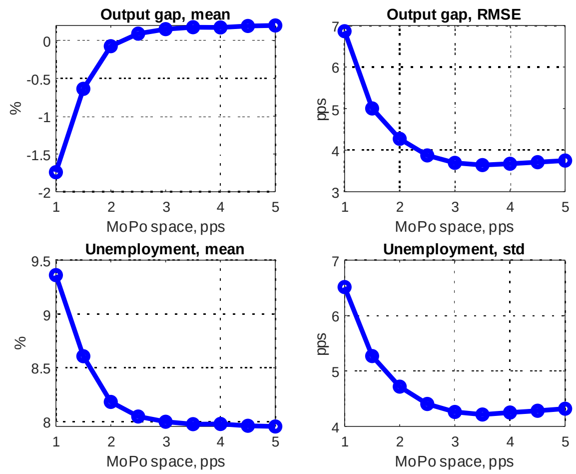

Figure 5: Monetary policy space and macro economic outcomes: the real economy

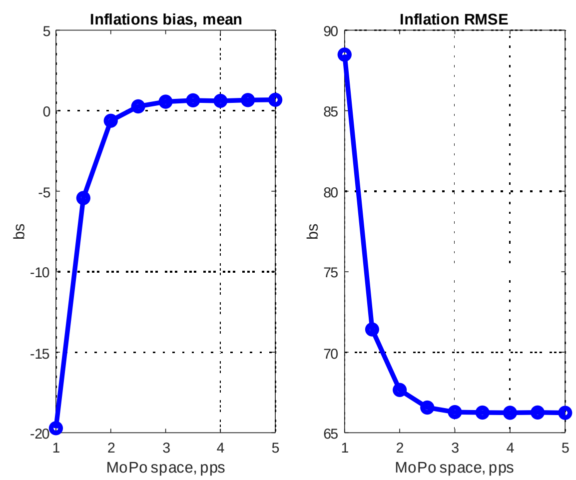

Figure 6: Monetary policy space and macro economic outcomes: inflation

more significant, when the monetary policy space becomes smaller (Figures 5-6). The average output gap over the business cycle(s) becomes negative (whereas without the ELB constraint it would be relatively close to zero), the average unemployment rate rises, and there is a negative bias in inflation (meaning that on an average inflation is lower than the central bank's inflation target); see the left panels of Figures 5 and 6. Also the standard deviation of unemployment and the root mean square error (RMSE) of the output gap (around the intended value of 0) and inflation (around the target) become larger with a smaller policy space; see the right panels of Figures 5 and 6. More generally, the distributions of the macro variables tend to become skewed due to the ELB: low realizations of inflation and the output gap, as well as high unemployment rates, become more frequent.

The relationship between the monetary policy space and the macroeconomic effects of the ELB is non-linear. When the policy space is 3 percentage points or wider, our simulation results suggest that the ELB does not matter so much for macro dynamics. However, if the space narrows from 3 percentage points, our results indicate that the possibility of being constrained by the ELB becomes an important issue.[4] This is partly due to the fact that the ELB binds more often (and the probability of it binding increases more than linearly), when the monetary policy space is narrower (Figure 1). In addition, the difference between the (negative) interest rate that would be implied by the baseline rule (1) and the constrained ELB value becomes more significant indicating that the ELB is an increasingly serious hindrance to policy accommodation (Figure 3). Also the average length of an ELB episode increases, as the monetary policy space gets narrower (Figure 4).

4. Inflation target range and the ELB

So far we have (implicitly) assumed that the central bank has a point inflation target - say annual inflation of 2%. This implicit assumption is imbedded for example in our baseline monetary policy rule (1). A central bank pursuing a point target, and following a rule such as (1) sets, ceteris paribus, high(er) interest rates if inflation is above the (point) target, and low(er) rates if inflation is below the

[4] Before the Financial crisis a monetary policy space of 4 or 5 percentage points was often perceived to be a good description of the prevailing circumstances. Afther the Financial crisis, a monetary policy space of 3 percentage points, or even tighter, has appeared to be a more likely estimate.

target. Moreover, a central bank following a (symmetric) point aim rule always reacts to changes in inflation with the same strength - measured essentially by coefficient β_π in rule (1) - whenever this is not prevented by the ELB.

While many central banks do in fact define price stability in terms of a point inflation target, this is clearly not the only possible option. Indeed, for example the Eurosystem's definition of price stability, medium run inflation below , but close to 2%, is not (de jure) a point target.

In this section we analyze one possible alternative, an inflation target range. The idea is that the central bank does not aim at a point target, but it has a range of values for inflation - say from 1% to 2% - that it considers to be consistent with its definition of price stability.

To operationalize this notion of price stability in our simulation exercises, we assume that the central bank reacts to changes in inflation less strongly when inflation is within the target range than when inflation lies outside the range. The idea is that as long as inflation remains inside the target range, the central bank should be rather happy with the prevailing situation. Then no radical changes in the prevailing monetary policy should be warranted. (However, when inflation is within the target range, the central bank can seek to stabilize the real economy. For the ECB this is a part of the secondary objective of monetary policy.)

To be still more concrete, in our simulations we assume that the inflation target range is 1 percentage point wide. When inflation is outside the target range, the central bank is assumed to follow the baseline monetary policy rule (1), with coefficients given in Table 1[5]. But when inflation is inside the target range, the central bank follows the monetary policy rule

$$\begin{aligned} \textit{interest rate}_t &= \rho * \textit{interest rate}_{t-1} \\ &\quad + (1-\rho)\Big[\widetilde{\beta}_\pi * \textit{inflation} \; + \beta_y * \textit{output gap} \\ &\quad +\beta_{ac} * \textit{gap accelerator} + \textit{natural rate} \;\Big] \\ &\quad + \textit{monetary policy shock} \end{aligned} \tag{3}$$

In particular, we assume that the coefficient of inflation $\widetilde{\beta}_\pi = 1.01$ is significantly lower than in the baseline rule (where $\beta_\pi = 2$); however since $\widetilde{\beta}_\pi > 1$ the Taylor

[5] To be more precise, outside the corridor, monetary policy reacts to *changes* in the relevant macro variables according to the baseline rule. In addition, we need to add an intercept to the rule, so that the reaction of monetary policy to inflation does not involve any discontinuities, and both the (baseline) rule applied outside the corridor and the rule applied inside the corridor give the same policy recommendation at the end points of the corridor. See also Figue 7 for an illustration.

principle is still satisfied. The values of the remaining coefficients ρ, β_y and β_{ac} are the same as in the baseline rule, and they are given in Table 1. The measure of inflation entering the rule (3) is one-year-ahead forecast of annual inflation, while the output gap is the current model-based output gap, just like in the baseline rule (1). [6]

Our aim is to analyze how the ELB constrains monetary policy and affects macroeconomic outcomes, when price stability is defined, or operationalized, as a target range for inflation. As above, in Section 2, we carry out the simulations with different assumptions concerning the width of monetary policy space.[7]

In the current setup, with the target range, we measure the monetary policy space as follows. The average (or normal) interest rate is the level that prevails if inflation lies (indefinitely) at the mid point of the target range (and natural rate is at its long-run average level, and the output gap is zero). This is also the steady state where the model converges if all shocks are shut down. Monetary policy space is the difference between the average (or normal) level of interest rates and the ELB. The setup with the target range, the ELB and the measure of monetary policy space is illustrated in Figure 7.

The main results from the simulations with the target range are presented in Figures 8, 9 and 10 (red curves in the figures). As a benchmark we also present simulation results with the baseline rule (blue curves in the figures).

The main observations are as follows. First, the incidence of the ELB is roughly the same under the target range rule as under the baseline - or point aim (Figure 8). As expected, the incidence of the ELB grows when the monetary policy space gets tighter.

Also in terms of real economic outcomes, measured by the output gap and the unemployment rate, the performance of target range rule appears to be comparable to that of the baseline rule (Figure 9). This is not very surprising, since the reaction of monetary policy to real economic outcomes, measured by the output

[6] We have conducted simulations with some alternative assumptions as well. For example, we have considered the possibility, that central bank simply keeps the interest rate constant when inflation is within the target range. In this setup we assume that the steady state (towards which the model converger if there are no shocks) lies at the upper bound of the target range. Hence we can carry out the simulation exercise without the Taylor principle applying within the target range. The results from these alternative settings are qualitatively similar.

[7] Technically, these simulations are carried out using the OccBin toolbox, with three occasionally binding constraints, and four different regimes, each regime corresponding to a linear segment in the piece-wise linear monetary policy rule (see Figure 7). We would like to thank Luca Guerrieri and Matteo Iacoviello for providing the OccBin codes needed in these simulations.

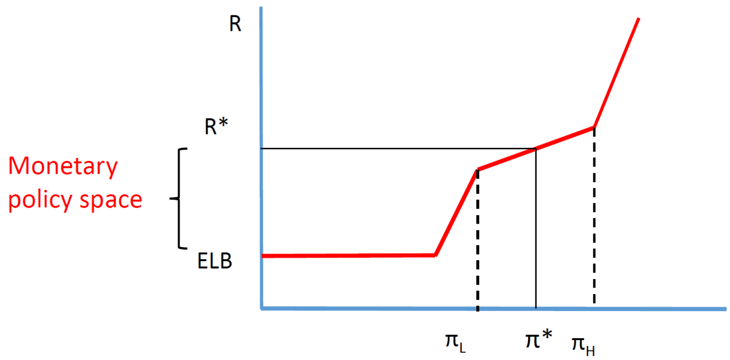

Figure 7: Monetary policy rule (in red) with a target range $[\pi_L, \pi_H]$ and an ELB. For illustrative purposes we assume here that the interest rate (R) reacts to inflation only.

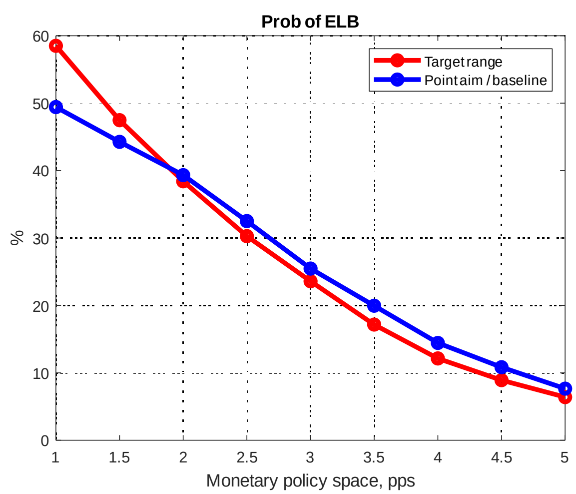

Figure 8: Indicence of the ELB under the target range rule and the baseline

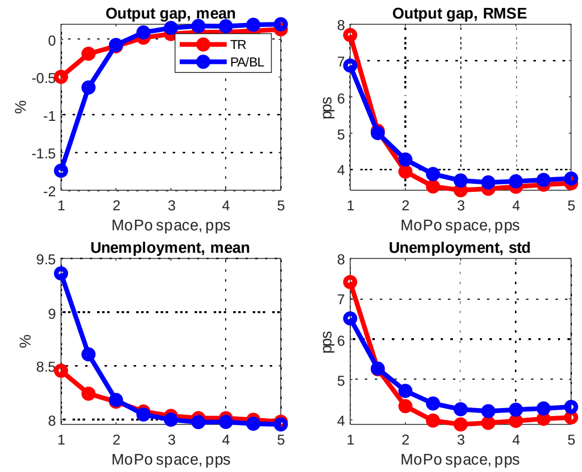

Figure 9: Output gap and unemployment under the target range rule (TR) and the point aim / baseline rule (PA/BL).

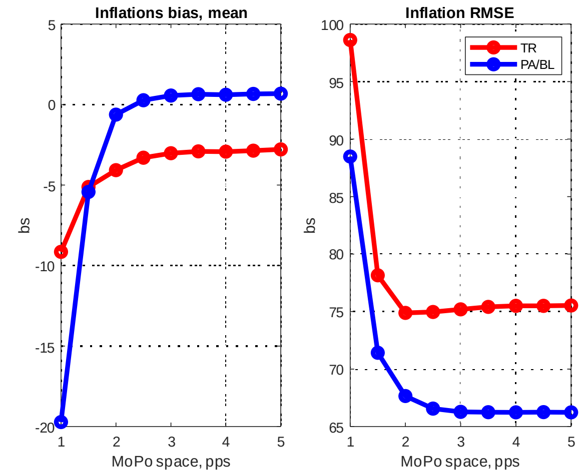

Figure 10: Inflation under the target range rule (TR) and the point aim / baseline rule (PA/BL).

gap, is identical under both rules. However, in terms of inflation, the target range rule tends to give rise to poorer outcomes: inflation is more volatile than under the baseline (Figure 10). Also this finding is rather intuitive, since inside the target range monetary policy reacts less strongly to changes in inflation. Hence, overall the target range rule appears to offer a worse trade-off between inflation stabilization and the stabilization of the real economy than the baseline (point aim) rule.

The only exception, where the ranking of the target range rule and the baseline is not as clear-cut, is the case where the monetary policy space is very tight, 1 pp, or 1.5 pp. Our simulation results suggest that in this situation the target range rule gives rise to a lower average unemployment rate (as well as smaller average negative output gap) and to a smaller negative inflation bias, than the baseline rule. - However, both inflation and the real economy are more volatile under the target range rule. - Under these circumstances, ELB binds very frequently both under the target range rule and under the baseline. However, under the target range rule, the segment between the ELB and the corridor essentially vanishes (see Figure 7 and think of moving the ELB upwards - or alternatively keeping ELB intact while moving the rest of the monetary policy schedule downwards), and whenever the ELB does not bind the central is typically within the target range where monetary policy reacts less aggressively to higher inflation. Hence under the target rule, the foregone accommodation due to the ELB is counterweighted by more accommodating policies when the ELB does not bind.

5. Low-for-long monetary policy rules

The results presented above suggest that the ELB may frequently bind in a low interest rate environment. The accommodation foregone due to the ELB may then entail significant economic costs. In this subsection we consider a number of alternative monetary policy rules suggested in the literature. These rules have the common feature that they involve policy makers committing in advance to keep rates "low for long" (L4L) when the ELB is hit. The general idea in this type of policies is to compensate for the accommodation that is forgone due to the ELB.

We assume that the policy regime is credible, and that households and firms fully understand it. Hence our analysis may be useful for evaluating how the economy would behave when the L4L policy regime has been in place for some time, so that households and firms have had time to learn, and trust, the regime. Our analysis may not be as helpful in assessing how the economy might behave immediately after the new regime has been announced or adopted.

The first rule we consider involves (so called) flexible price level targeting (Bernanke, Kiley and Roberts (2019)). The baseline monetary policy rule (1) is augmented with a price level term:

$$\begin{aligned} \textit{interest rate}_t &= \rho * \textit{interest rate}_{t-1} \\ &\quad + (1-\rho)\left[\beta_\pi * \textit{inflation} + \beta_y * \textit{output gap}\right. \\ &\quad + \beta_{ac} * \textit{gap accelerator} + \textit{natural rate} \\ &\quad \left. + \beta_{pl} * \textit{price level}\right] + \textit{monetary policy shock} \end{aligned} \tag{4}$$

All the variables in the rule are deviations from their steady state or trend values. In particular the new (compared to the baseline) price level term implies that the central bank reacts to deviations of the price level from its trend, where the trend is implied by the central bank's inflation target (for example a 2% inflation target implies that the trend price level grows at an annual rate of 2%). In the simulations, we assume that the price level (gap) is given the same weight as inflation (forecast one year ahead); hence $\beta_{pl} = \beta_\pi = 2$. The remaining parameter values are as in the baseline rule and they are given in Table 1. The central bank is assumed to set its monetary policy according to the rule (4) if the implied interest rate is above the ELB. If the ELB constraint is binding interest rate$_t = ELB$.[8]

Next, we consider a rule that involve (flexible) medium term inflation targeting. Here the baseline monetary policy rule (1) is augmented by past average inflation

$$\begin{aligned} \textit{interest rate}_t &= \rho * \textit{interest rate}_{t-1} \\ &\quad + (1-\rho)\left[\beta_\pi * \textit{inflation} + \beta_y * \textit{output gap}\right. \\ &\quad + \beta_{ac} * \textit{gap accelerator} + \textit{natural rate} \\ &\quad \left. + \beta_{p\pi} * T * \textit{average past inflation}\right] + \textit{monetary policy shock} \end{aligned} \tag{5}$$

The term past inflation refers to the deviation of average past medium-term inflation from the inflation target. Here we interpret "medium-term" to mean four-year

[8] We have also experimented with pure(r) forms of price level targeting, where the central bank only reacts to deviations of the price level from its trend (i.e. the monetary policy rule does not involve inflation (as opposed to the price level), real activity or the natural rate). However, these rules turned out to perform rather poorly, resulting in highly volatile macroeconomic outcomes. In addition, we have experimented with flexible price level rules where the price level is given a lower, or higher weight. These simulations suggest that giving the price level a high (enough) weight tends to result in better outcomes.

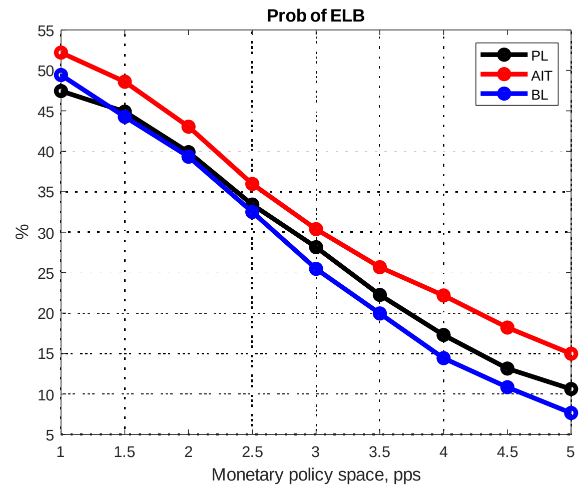

Figure 11: Incidence of the ELB. Flexible price level targeting (PL), flexible average inflation targeting (four-year average, AIT) and baseline (BL).

average inflation. (We have also conducted simulations with two-year and three-year average inflation. However, these rules tend to perform worse than the rule with four-year average inflation.) We assume that past average medium run inflation is given the same weight as the (one-year-ahead) inflation forecast; hence $\beta_{p\pi} = \beta_{\pi} = 2$. However, notice that the average past inflation is also multiplied by the length (T) of the time period over which the average is computed. In our case $T = 16$ quarters (4 years). Intuitively, longer-run means tend to vary less over time; this is then compensated by giving longer-term averages a larger weight in the rule.[9] The remaining parameter values are as in the baseline rule and they are given in Table 1. The central bank is assumed to set its monetary policy according to the rule (5) if the implied interest rate is above the ELB. If the ELB constraint is binding, interest rate$_t = ELB$.[10]

The key findings from the simulation exercises with flexible price level targeting and average inflation targeting are presented in Figures 11 - 13. The first observation is that monetary policy is at the ELB somewhat more often under

[9] Here our rule follows the recent simulation exercises coordinated by the Bank of International Settlements (BIS).

[10] We have also experimented with flexible medium term inflation targeting rules where the average past inflation is given a lower, or higher, weight. These simulations suggest that giving the average past inflation a high (enough) weight tends to result in better outcomes.

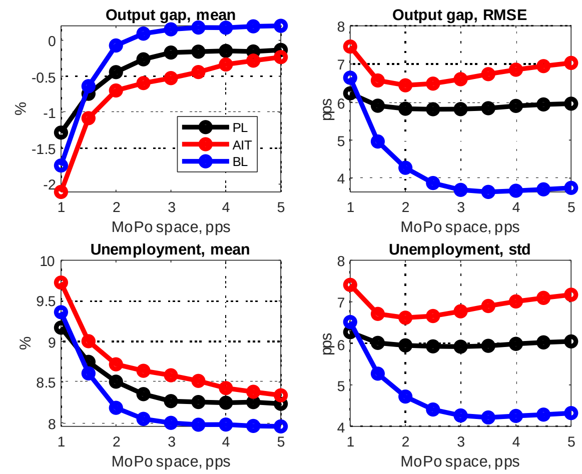

Figure 12: Output gap and unemployment under flexible price level targeting (PL), flexible arverage inflation targeting (AIT) and the baseline rule (BL).

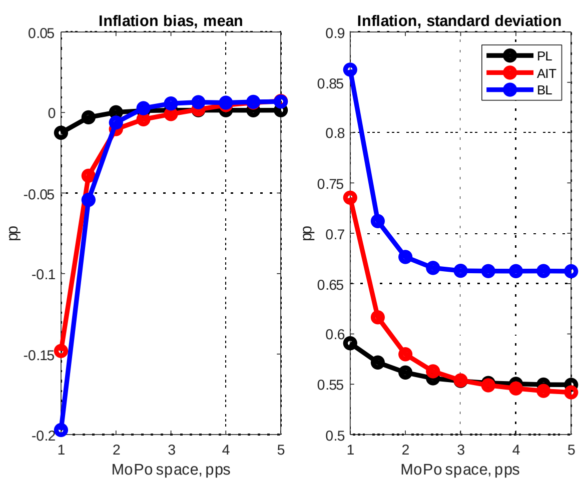

Figure 13: Inflation under flexible price level targeting (PL), flexible average inflation targeting (AIT) and baseline (BL).

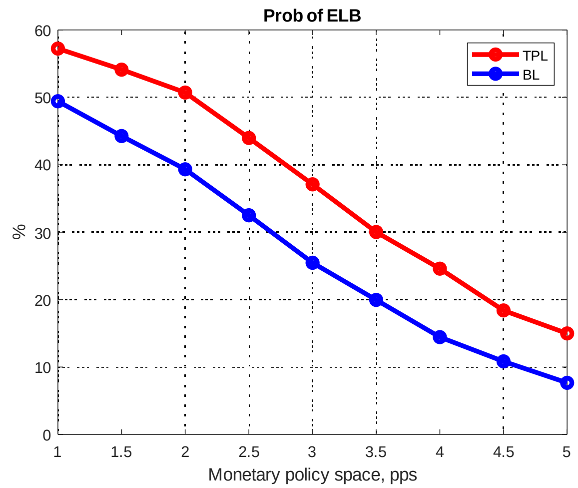

Figure 14: Indicence of the ELB under termporary price level targeting (TPL) and the baseline (BL).

the alternative rules than under the baseline rule (Figure 11). This is hardly surprising, since the key idea of these rules is to keep interest rates low for longer.

The second observation is that flexible price level targeting and flexible average inflation targeting stabilize inflation, compared with the baseline rule - the RMSE is lower (Figure 13). Also this is natural, since these L4L rules not only make up for forgone accommodation, but they also put more weight on inflation dynamics.

The third observation is that flexible price level targeting and flexible average inflation targeting appear to achieve stabler inflation at the cost of higher volatility in the real economy (the unemployment rate and the output gap), compared with the baseline (Figure 12). This is the case in particular when the monetary policy space is relatively wide. The underlying reason is that the make-up strategies, which react to past inflation developments, also entail the central bank giving a lower relative weight to the real economy in the policy rule. However, when the monetary policy space is (very) tight, these rules (and especially flexible price level targeting) provide a better trade-off between stabilizing the nominal and the real side of the economy: inflation is more stable than under the baseline rule, and the real side is roughly as (un)stable as under the baseline rule. Under these conditions the ELB imposes a stringent constraint on the central bank's ability to steer the economy. Then low-for-long policies that compensate for the forgone accommodation are highly useful.

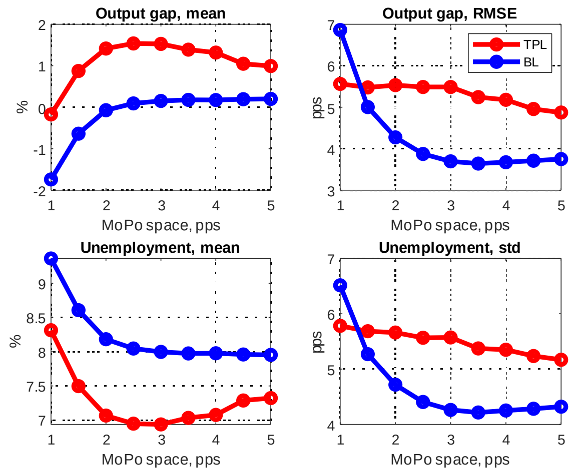

Figure 15: Output gap and unemployment under temporary price level targeting (TPL) and the baseline (BL).

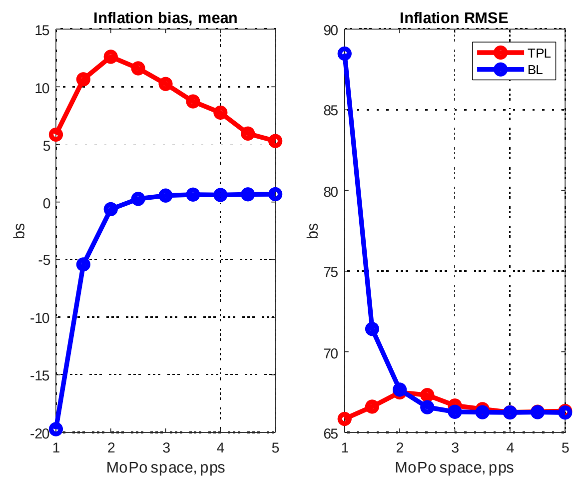

Figure 16: Inflation under temporary price level targeting (TPL) and the baseline (BL).

The rules involving flexible price level targeting (4) and flexible medium term inflation targeting (5) imply that the central bank reacts to both positive and negative past deviations of inflation from its target. Hence these rules entail not only keeping interest rates "low for long", but also "high for long" (after episodes of past inflation overshooting the target). Next, we consider a threshold-type policy rule which involves the central bank committing to keeping rates "low for long", but without the corresponding commitment to keeping them "high for long".

The threshold-type policy we analyze is known as temporary price-level targeting. As discussed by Bernanke (2017), this rule implies that policy makers commit to deferring exit from the ELB at least until any shortfall in inflation over the entire ELB period is fully made up. Away from the ELB, the central bank follows the baseline Taylor rule (1).

The findings from the simulation exercises with temporary price level targeting are presented in Figures 14 - 16. Overall, the key observation is that temporary price level targeting tends to give rise to more accommodating policies than the other rules (BL, PLT, AIT). The ELB binds more often (Figure 14), the unemployment rate tends to be lower (Figure 15), the average output gap tends to be positive (Figure 15), and there is typically a small positive inflation bias (Figure 16). Like the other L4L rules, temporary price level targeting tends to perform well, compared with the baseline, when the monetary space is small. This is rather intuitive: if the ELB seriously constrains the central bank's ability to pursue accommodative policies, a rule that involves "low for long" but not "high for long" can be a good remedy.

6. Concluding remarks

In this paper we analyzed the economic performance of different monetary policy strategies, or rules, in a low interest rate environment, using simulations with a DSGE model which has been estimated for the euro area. We presented three sets of results.

First, the macroeconomic costs of the effective lower bound of interest rates (ELB) are likely to grow in a non-linear manner if the monetary policy space (the difference between the normal, or average, level of nominal interest rates and the ELB) shrinks. The ELB binds more frequently, and the ELB episodes become longer; the volatility of real activity, unemployment and inflation increases; the downward bias in (average) inflation becomes more pronounced, the average unemployment rate rises and the average output gap becomes more negative. If the monetary policy space shrinks from 4 percentage points to 3 pps, our simulations suggest that the macroeconomic dynamics may not change that much. However, if the monetary policy space further shrinks from 3 to 2 pps, and perhaps further to 1 pp , the induced increase in macro volatility can be much more substantial.

Second, a point inflation target appears to outperform a target range in terms of macroeconomic outcomes. Under the target range, inflation is more volatile, while both strategies result in roughly similar outcomes for the real economy.

Third, low-for-long monetary policy rules may alleviate the problems caused by the ELB. However, there are some caveats. The low-for-long rules we have considered involve the central bank paying attention to past inflation. Hence while these rules entail the central bank making up for forgone accommodation, they also put more weight on inflation. Our simulation results indicate that the (relative) performance of L4L rules depends on the size of the monetary policy space. These rules tend to perform well, relative to the baseline flexible inflation targeting rule, if the monetary policy space is small. Under these circumstances the ELB constitutes a truly serious constraint to monetary policy and the accommodation provided by make-up strategies is highly useful. However, if the monetary policy space is larger, the L4L rules, while stabilizing inflation, may result in more volatility in the real economy.

Finally, we should acknowledge and discuss some of the limitations of our study. There are evidently some important aspects that we have left aside. One such issue is expectation formation. Throughout we have assumed that the economic agents have rational, or model consistent, expectations. While this assumption may be a good approximation in the long-run if the structure of the economy (including public policies) is stable enough, it is probably more problematic over periods of transition, when the public is still learning to live with the new set of policies, and these policies may not be fully credible.

A second related issue is the possible deanchoring of (medium and long run) inflation expectations. We have (at least implicitly) assumed that the central bank's inflation target is fully credible and succeeds in anchoring the public's inflation expectation. Furthermore, in the simulations we have assumed that the economy cannot be indefinitely stuck in a liquidity trap. In other words, (when choosing to conduct the simulations with a piecewise linear model and the OccBin toolbox) we have in practice ruled out the possibility of multiple equilibria (and multiple steady states): if the economy is not buffeted by shocks, it eventually returns to the intended steady state. When these caveats are taken into account, one could perhaps argue that our results on the macroeconomic costs of the ELB should be treated as a lower bound, or as conservative estimates. If inflation expectations are deanchored, or if the economy is indefinitely stuck in a liquidity trap, the macroeconomic costs could be significantly larger.

Thirdly, one should acknowledge that the central bank is operating in an environment with imperfect information. For example, cyclical indicators, such as the output gap or the time-varying natural rate (which enter our baseline rule) are estimated subject to a significant amount of noise (and these estimates tend be updated over time, rendering real-time decision making even harder). Even the measurement of inflation, the prime interest of most modern central banks, is problematic, and it is not always clear what notion of inflation one should focus on. In our analysis we assumed that all these key macroeconomic variables and indicators can be observed or estimated without problems. Then one of our conclusions was that a monetary policy which targets a precise point-wise inflation aim outperforms a monetary policy strategy that targets a less precise object, a target range. If the problems of uncertainty and measurement were taken into account, our verdict might be less clear-cut.

A final, and very general, methodological observation is that all macro models are simplifications of the economic reality, and results and policy recommendations are at least to a certain extent model specific. Then it is important to assess the possible implications of different policies using a wide suite of different economic models: hopefully a set of relatively robust conclusions emerges. This paper aims at contributing to the on-going Eurosystem-wide efforts to discuss, analyze and evaluate the monetary policy strategies available to the euro area.

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