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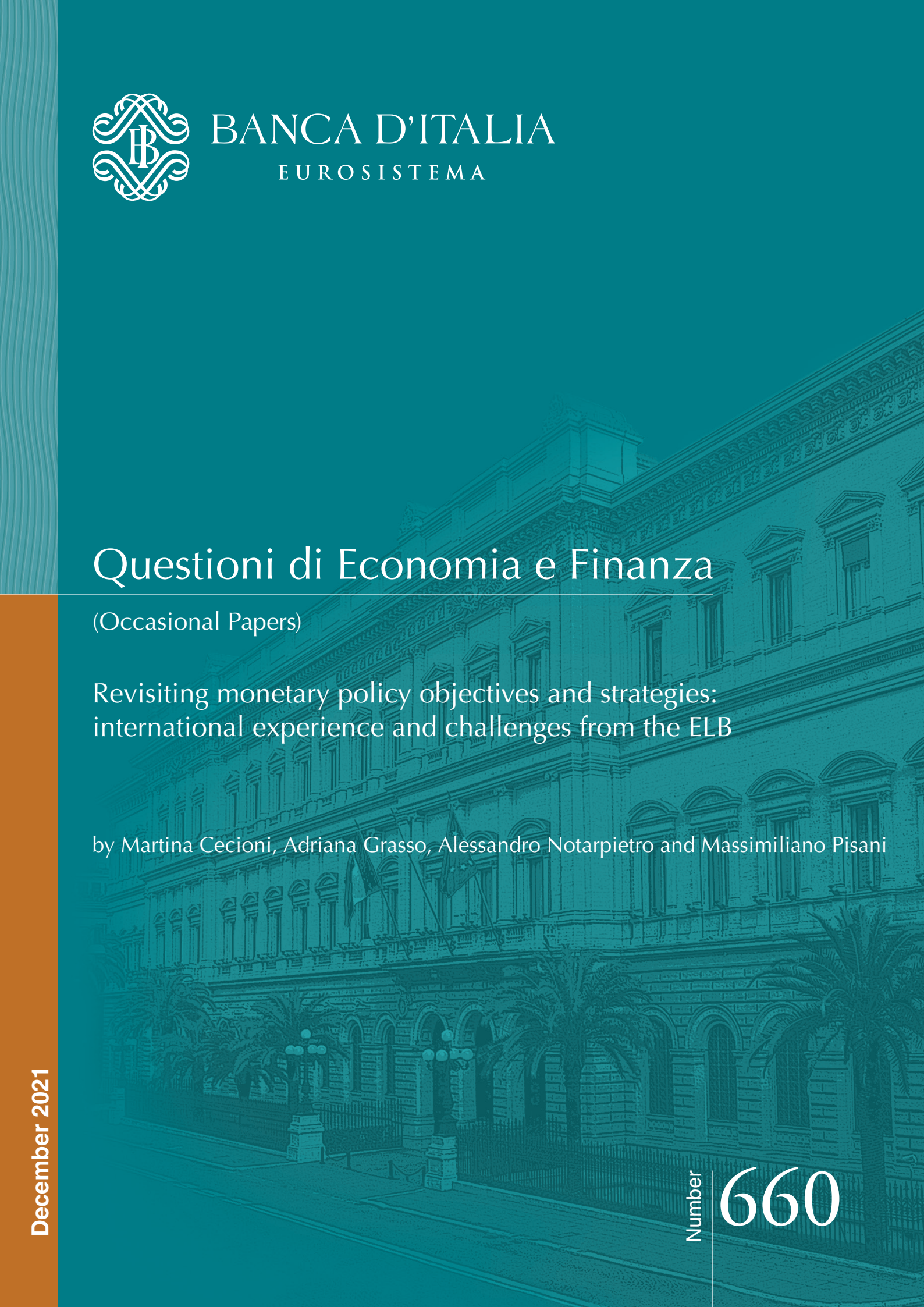

December 2021

Number 660

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The series is available online at www.bancaditalia.it .

ISSN 1972-6627 (print)
ISSN 1972-6643 (online)

Printed by the Printing and Publishing Division of the Bank of Italy

REVISITING MONETARY POLICY OBJECTIVES AND STRATEGIES: INTERNATIONAL EXPERIENCE AND CHALLENGES FROM THE ELB

by Martina Cecioni*, Adriana Grasso°, Alessandro Notarpietro* and Massimiliano Pisani*

Abstract

We review the experience of central banks in 12 advanced economies in formulating their price stability objectives during the last 20 years. All central banks under review target a small and positive inflation rate (typically 2%). In most cases, they set a point target, in some a range or a point with bands around it. Range and bands are more common among small open economies. We also conduct a model-based analysis of the macroeconomic performance of different monetary policy strategies when the policy rate is constrained by the effective lower bound (ELB). Under standard inflation targeting, inflation remains, on average, below target (disinflationary bias). ELB incidence and duration are higher the lower the target. A point inflation target performs better than a range, especially if compared to an asymmetric one with the focal point close to the ceiling. Makeup strategies (price level targeting and average inflation targeting) and asymmetric inflation targeting strategies, in which the central bank's reaction to below-target inflation is stronger compared with the case of above-target inflation, reduce the disinflationary effects of the ELB and have better macroeconomic stabilization properties compared with standard inflation targeting.

JEL Classification: E31, E32, E52, E58.
Keywords: central banking, monetary policy rules, effective lower bound.
DOI: 10.32057/0.QEF.2021.0660

Contents

* Bank of Italy, DG Economics, Statistics and Research

° European Central Bank, DG Monetary Policy

1. Introduction[1]

The gradual and persistent decline in the real 'equilibrium' interest rate (the so-called 'natural rate of interest', labelled as r*) has challenged the ability of central banks to provide the necessary accommodation by conventional interest rate policy. Structurally lower interest rates have indeed increased the likelihood of the policy rate hitting the effective lower bound (ELB) in response to disinflationary shocks.[2]

In the last two years, the Federal Reserve and the European Central Bank (ECB) have reviewed their monetary policy strategies also to cope with this challenge. For the ECB, an additional motivation to review its strategy was related to concerns that the price stability definition could be problematic when disinflationary shocks prevail and the ELB is more likely to bind. Price stability had been defined in 1998 as "*a year-on-year increase in the Harmonised Index of Consumer Prices (HICP) for the euro area of below 2%*". In 2003, the Governing Council clarified that, within the range 0-2% of the price stability definition, it aimed at inflation "*below but close to 2%*". This double-key formulation of the price stability objective, the lack of a precise numerical value for the inflation aim and the location of the aim close to the ceiling of the price stability interval have induced perceptions of an asymmetry of the framework (i.e. the perception that the ECB was more worried by upward deviations from the target than by downward deviations). In the too-low-for-too-long inflation environment of the last ten years this might have contributed to creating a concrete risk of a de-anchoring of long-term inflation expectations to the downside (Bulligan et al., 2021 and Corsello et al., 2021). In such an environment, if inflation runs below the objective following economic downturns, but hardly moves above 2 per cent when the economy is strong, it will average less than 2 per cent over time and expectations would drift below the target (Rostagno et al., 2019).[3]

In this paper, we first revisit the monetary policy strategies adopted by central banks of advanced economies over the last 20 years focusing on their inflation objectives. Subsequently, we simulate a

[1] We thank Michele Caivano, Paolo Del Giovane, Giuseppe Ferrero, Alessandro Secchi, and Stefano Neri for helpful comments. The analyses in this paper were prepared as background material for the Eurosystem Workstream on Price Stability Objective. See Cecioni et al., (2021). All errors remain our own. The views expressed are our own and do not necessarily reflect those of the Bank of Italy, the ECB, or the Eurosystem. Email addresses: Martina.Cecioni@bancaditalia.it; Adriana.Grasso@ecb.europa.eu; Alessandro.Notarpietro@bancaditalia.it; Massimiliano.Pisani@bancaditalia.it.

[2] According to Wicksell (1898), the natural rate of interest is the real interest rate that balances desired saving and planned investment. The decline in the natural rate across many advanced countries is due to slow-moving structural factors, such as an ageing society and lower trend productivity growth, which have led to an abundant supply of savings facing a muted investment demand. For an analysis of the natural rate of interest in the euro area see Brand et al., (2018).

[3] The authors of the paper argue that the estimated asymmetric response may have been beneficial in keeping inflation in check in the face of the prevailing inflationary pressures hitting the euro area in the first ten years of the ECB's existence (1999-2008). But they emphasize that it may have contributed to persistently low inflation when shocks turned disinflationary after the global financial crisis and the sovereign debt crisis in some euro area countries.

dynamic stochastic general equilibrium (DSGE) model to assess the effectiveness of alternative monetary policy strategies in achieving the inflation target and stabilizing inflation and output when the ELB limits the scope for reductions in the policy rate.

In the international overview, we discuss the monetary policy frameworks in terms of the level, the horizon and the formulation of the price stability objectives. We describe how these frameworks evolved over time, also in response to the challenges posed by the current macroeconomic environment, characterized by structurally low interest rates.

We report that central banks in advanced economies choose to target a small and positive inflation rate, which in most cases is set around 2%. A few central banks changed the level of their target in recent years; several have recently clarified the symmetry of their targets. Central banks formulate their inflation objective in a variety of ways: most of them use point targets, some use a range, others a point with bands around it. Range targets and bands are more common among small open economies. Over time, central banks that changed the formulation of their target went in the direction of sharpening it. Central banks that moved to explicit numerical targets only in recent years (Federal Reserve and Bank of Japan) opted for a point target. Explicit communication has been used to clarify that ranges and bands are not inaction regions or tolerance zones. Almost no central bank specifies a horizon for the achievement of the objective in order to retain some flexibility. Most of them define the horizon as the "medium term".

In the model-based analysis, we evaluate alternative strategies in an environment in which the natural rate is structurally low and the probability of hitting the ELB is non-negligible, using a medium-scale DSGE model for the euro area. According to the academic literature the ELB induces a downward bias to inflation under standard inflation targeting (IT) strategies (Hills et al., 2019). We assess the macroeconomic stabilization properties of various strategies aimed at contrasting this disinflationary bias in such an environment.

First, we consider IT policies under alternative levels of the inflation objectives. Some studies argue that, facing a lower natural rate, the central bank should set a higher inflation objective (Andrade et al., 2020 and Blanchard et al., 2010). If credible, the higher inflation target would lead to a corresponding increase in the average nominal interest rate, giving the central bank more space to cut the policy rates, when needed.

Second, we explore the performance of a range-targeting regime with a focal point for inflation. Several central banks indeed define their inflation objectives in terms of a range of values that they

consider consistent with price stability. We focus on both symmetric and asymmetric ranges around a focal point target.

Third, we study various makeup strategies (i.e., monetary policies which take into account the past shortfall of inflation from the target), such as price level targeting (PLT), backward average inflation targeting (AIT), and temporary price level targeting (TPLT). According to the literature, makeup strategies could substantially reduce the costs of ELB episodes (Bernanke et al., 2019; Mertens and Williams, 2019; Bernanke, 2017; Kiley and Roberts, 2017) and increase welfare (Nakata et al., 2020). If the public understands and believes the central bank's promise to deliver higher inflation after a period of below-target inflation, the expectation of a more expansionary policy and rapid output growth in the future should mitigate the decline in output and inflation during ELB periods and reduce their frequency and duration.

Finally, as an alternative to makeup policies, we analyse the properties of asymmetric rules under which the central bank reacts more to below-target than to above-target inflation. Bianchi et al., (2021) show that - by responding less aggressively to shocks that push inflation above the target than to shocks that push it below the target - the distribution of inflation outcomes shifts up, thereby offsetting the downward bias determined by the ELB and aligning expected inflation with the target.[4]

Our model-based simulations show that when the natural rate is low and the probability of hitting the ELB is large, a standard IT approach can lead to actual inflation being on average below target (*disinflationary bias*). The incidence and duration of the ELB and its consequences on inflation are higher the lower is the inflation target. Moreover, having a (perceived) asymmetric range around a focal point close to the ceiling can exacerbate the problem. In such an environment, makeup strategies are more effective than IT. Among them, the PLT regime shows the best performance in terms of inflation stabilization, followed by AIT and TPLT. Finally, an asymmetric strategy according to which monetary policy reacts more strongly to below-target than to above-target inflation and tolerates temporarily above-target inflation can reduce the disinflationary bias, as it raises the probability of inflation on the upside and, in doing so, offsets the downside risk due to the ELB.

The rest of the paper is organized as follows. Section 2 reviews the experience of advanced economies' central banks with their price stability objectives. Section 3 illustrates the results of simulations of a DSGE model for the euro area in which the ELB binds. Section 4 concludes.

[4] In the US, the new monetary policy framework announced in August 2020 has both a makeup element and an asymmetric one. For a discussion of the academic literature from a policy perspective, see Evans (2021).

2. International experience on price stability objectives

In this section we review the price stability objectives adopted by several central banks in advanced economies over the last 20 years focusing on the level of the inflation targets, the horizon over which price stability is to be achieved, and the formulation of their objectives (in terms of a range or a point with or without bands). We describe how these frameworks evolved over time and, more recently, also in response to the challenges posed by the macroeconomic environment, characterized by low inflation and the presence of long-lived episodes of key policy rates at the ELB.

We review the experience of the following 12 central banks: Bank of Canada (BoC), Bank of England (BoE), European Central Bank (ECB), Bank of Israel (BoI), Bank of Japan (BoJ), Czech National Bank (CNB), Federal Reserve System (Fed), Norges Bank (NB), Reserve Bank of Australia (RBA), Reserve Bank of New Zealand (RBNZ), Sveriges Riksbank (SR) and Swiss National Bank (SNB). All these central banks have explicit numerical objectives for inflation, although their monetary policy frameworks differ for what concerns the level, the horizon over which price stability is to be achieved, and how their objective is formulated (in terms of a range or a point with or without a band).

The rest of the section is organized as follows: section 2.1 discusses the level of the inflation target; section 2.2 the horizon over which the relevant measure of inflation has to be brought back to its objective; section 2.3 overviews the formulation of the price stability objective. Throughout the sections, we also discuss the changes to the monetary policy frameworks that central banks undertook in the last 20 years.

2.1 The level of the target

All central banks under review have explicit numerical price objectives. The BoJ and the Fed were the last ones that adopted a numerical definition, both in 2012. Central banks have chosen to target a small and positive inflation rate for several reasons. First, to have a safety margin against the risks of deflation; having such a margin is important because there are limits to how much the key policy rates can be reduced (i.e., because of the ELB). Setting the inflation target slightly positive instead of zero implies that, on average, the nominal interest rate is higher and thus the central bank has more room to reduce interest rates to contrast downward shocks to inflation and stimulate aggregate demand. Second, central banks take into account that the measure of targeted inflation, most commonly the consumer price inflation, is in general found to slightly overstate true inflation because

of a small but positive bias in the measurement of price level changes. Lastly, a small and positive inflation rate also facilitates the necessary adjustments in relative prices and wages.[5]

Most central banks have a target which is set at 2% (BoJ, NB, BoE, Fed; Table 1) or which is centered around the same number (SR, BoI, RBNZ, CNB, BoC); exceptions are the RBA, which has a slightly higher target (2 to 3%), and the SNB, which has a lower target (between 0 and 2%, i.e. "*a rise in the Swiss consumer price index (CPI) of less than 2% per annum*").

In 1998, the Governing Council of the ECB defined a price stability range ("*a year-on-year increase in the Harmonised Index of Consumer Prices (HICP) for the euro area of below 2%*") and, in its review of 2003, clarified that, in order to fulfil its price stability objective, the Governing Council aims to maintain HICP inflation "*below but close to 2%*". After the strategy review of July 2021, the ECB has an inflation target of 2%.

Understandably, changes to the level of the inflation target are not very frequent. Among those under study, four central banks changed the level of their inflation targets over the last two decades. Three of them lowered it: the CNB reduced its target from 3% to 2% in 2007 (effective starting 2010) as part of the process of the convergence of its economy towards the advanced economies.[6] NB reduced its target from 2.5% to 2% in 2018, as it expected lower future inflation due to domestic structural factors and a downward trend in prices of tradable commodities.[7] Finally, the BoE reduced its target from 2.5% to 2% in 2003 when it changed the measure of targeted inflation (from the Retail Price Index to the CPI).

The decline in the interest rates and the low-inflation environment prevailing in the last decades has led some central banks to rethink their objectives and their monetary framework more in general to account for the challenges coming from the ELB on the conventional policy instrument. The BoJ is a special case because it has been facing a deflationary macroeconomic environment for two decades and it is the only one, among those under review, which has increased its "price stability target" in an effort to end deflation: in 2013, the BoJ replaced its "goal" of 1% to a "target" of 2% in an effort to raise actual and expected inflation. The BoJ stated that "*the newly-introduced "price stability target" is the inflation rate that the Bank judges to be consistent with price stability on a sustainable basis*".[8]

[5] Bank of Canada (2016) indicated that an additional reason for targeting a small and positive inflation rate was the presence of downward nominal wage rigidity in the economy.
[6] For the CNB announcement in 2007, see https://www.cnb.cz/export/sites/cnb/en/monetarypolicy/.galleries/strategic_documents/inflacni_cil_cnb_en_2010.pdf
[7] "*Modernisation of the Regulation on Monetary Policy*". Norges Bank's letter to the Ministry of Finance. Feb. 2018 https://www.norges-bank.no/en/news-events/news-publications/Submissions/2018/18-02-28-submission/
[8] *The "Price Stability Target" under the Framework for the Conduct of Monetary Policy*. Bank of Japan release. January 22, 2013 https://www.boj.or.jp/en/announcements/release_2013/k130122b.pdf

Previously, the BoJ had reported information on the range and midpoint of the inflation rates that Policy Board members viewed as consistent with price stability and had adopted an explicit inflation objective of 1% in February 2012 for the first time (see also Nakata, 2020).

The BoC reviews some aspects, deemed relevant for the years to come, of its monetary policy framework every 5 years. During the 2016 review, one of the questions on which it focused was "*Should the 2 per cent inflation target be increased?*" against the background of declining natural rates and concluded that "*the arguments for maintaining the 2 per cent target [are] compelling and the evidence does not justify a change in the target at this time*" (Bank of Canada, 2016).

The 2020 Fed strategy review took as given that inflation at a rate of 2 per cent is most consistent over the longer run with its mandate.

Facing a low-interest rates and low-inflation environment, most central banks have (re)affirmed their intention to achieve the price stability objective in a symmetrical way, signaling their concern for both inflation that is persistently too high and inflation that is persistently too low with respect to the target. For example, the Deputy Governor of NB stated in 2000 that "*Over time, symmetry in setting interest rates is important in the sense that the instrument must be used with the same force, both for curbing and stimulating growth in the economy. This symmetry is necessary to maintain confidence in nominal stability*";[9] since 2015, the Remit for the Monetary Policy Committee for the BoE specifies that "*the inflation target of 2 per cent is symmetric*".[10] In 2016 the Federal Open Market Committee (FOMC) clarified that the Fed's inflation target is symmetric;[11] the same year, the BoC reiterated this message while renewing its inflation-control target. In July 2019 the ECB affirmed in its Introductory Statement "*its commitment to symmetry in the inflation aim*";[12] after its 2021 strategy review the ECB re-affirmed the importance of a symmetric objective.

[9] "*Monetary policy experiences and challenges for the central bank*", Address by Deputy Central Bank Governor Jarle Bergo Gausdal, Jan. 2000 https://www.norges-bank.no/en/news-events/news-publications/Speeches/2000/2000-01-27/

[10] The Bank of England Act 1998 requires the Treasury to specify at least once every 12 months how price stability will be defined. For the first time in 2015 the remit specified "*The inflation target is symmetric: deviations below the target are treated in the same way as deviations above the target*."

[11] "*Statement on Longer-Run Goals and Monetary Policy Strategy*", FOMC, Jan. 2016 https://www.federalreserve.gov/monetarypolicy/files/FOMC_LongerRunGoals_20160126.pdf

[12] Governing Council meeting of July 25, 2019. *Introductory Statement*, by Mario Draghi, President of the ECB https://www.ecb.europa.eu/press/pressconf/2019/html/ecb.is190725~547f29c369.en.html.The symmetry of the objective was not stated for the first time in 2019, but has been stressed in recent years. For example, during the February 2014 press conference, the ECB President replied to a question about the symmetry of the inflation objective on the downside by recalling that the central bank did not "*have a cool attitude at all with respect to the present level of inflation rates […] these levels of inflation for a protracted period of time, are a risk on their own […] so, we [still] have a symmetric attitude.*" In June 2016 President Draghi had indicated it as well (see the speech "*Delivering a symmetric mandate with asymmetric tools: monetary policy in a context of low interest rates"*, M. Draghi, 2 June 2016).

In its latest Statement on Longer-Run Goals and Monetary Policy Strategy, updated after the strategy review terminated in August 2020, the Fed made a further step and acknowledged the need of an asymmetric framework to achieve symmetric outcomes for inflation given the constraints imposed by the ELB.[13]

2.2 The horizon for the conduct of monetary policy

For some of the central banks the horizon at which inflation must be brought back to target is defined as "the medium term" without further clarification (this holds true for 4 out of the 12 central banks under review, i.e. the RBA, NB, the RBNZ, the ECB, and the CNB; Table 1). The medium-term horizon gives monetary policy the flexibility to look through to temporary shocks to inflation and minimize volatility in economic activity and takes into account the lags of transmission of monetary policy. Other central banks provide a more precise indication of the horizon: the SNB sets the "medium term" explicitly at three years, the BoI at "*within two years*", and the BoC at "*six to eight quarters, on average*".

Some other central banks have chosen not to specify the monetary policy horizon altogether: the SR gives no information, neither qualitative nor quantitative; the Fed in its Statement on Longer-Run Goals and Monetary Policy Strategy indicates that "*The Committee judges that inflation at the rate of 2 percent […] is most consistent over the longer run with the Federal Reserve's statutory mandate*". In both cases, though, observers usually infer that the horizon is the one of the projections that both central banks publish (two years for the SR and three years for the Fed).

A different case is the one of the BoJ, which in January 2013, when it changed its target, switched from a medium-term orientation to "*at the earliest possible time*". The BoE also has an uncommon definition of the horizon, as the remit for the Monetary Policy Committee (MPC) states that BoE is required to keep inflation at target "*at all times*", and the Governor must send an open letter to the Chancellor addressing the horizon over which the MPC judges it is appropriate to return inflation to the target should this deviate by ±1pp from it.

The central banks that are more explicit in the definition of the horizon put some effort in communicating that this must be considered with some flexibility. For example, the BoC in its website states that "*specific occasions may arise in which a somewhat shorter or longer time horizon might be appropriate*". A number of the central banks that specify a particular time frame (BoC and SR)

[13] Fed Vice Chair R. Clarida stated that "the new framework is asymmetric", see Clarida (2020a). Clarida also stated that "In other words, the aim to achieve symmetric outcomes for inflation requires an asymmetric monetary policy reaction function in a low r* world with binding ELB constraints in economic downturns", see Clarida (2020b).

have emphasized that their horizons may be nearer or more distant depending on the shocks hitting the economy and the need to meet other goals.

2.3 The formulation of the objective

Central banks have chosen different formulations of their objective. We can classify them in three groups, each of them with some heterogeneity within: (i) central banks that have point target objectives: Fed, BoJ, BoE, NB, and, since 2021, ECB; (ii) central banks that have a range target, without indicating any desired aim or focal point within it: RBA, SNB, and BoI; (iii) central banks that have a mix of previous formulations, with a focal mid-point within a range (BoC, RBNZ) or within symmetric bands (CNB and SR).

A point target (group i) is usually justified on the grounds of simplicity. A single number is easier to communicate and provides a more precise benchmark for the setting of prices and wages. Hence, it is thought to be conducive to a more effective anchoring of inflation expectations.[14]

Among the central banks that belong to group (ii) and (iii), the emphasis on the meaning and importance of the range is different and has changed over time. All central banks that do not have a point target indicate that the choice of a range target aims at conveying the idea that inflation is volatile and that it is not possible to fine-tune it to a specific number in the short run. Central banks that are in group (iii) justify their choice by indicating that the mid-point or focal point provides a clear signal of the objective while transparently communicating that any inflation target is pursued with the flexibility required for absorbing temporary shocks.[15] Within each group, there are however interesting differences in the details of the formulation and how it evolved over time.

Central banks with point targets - The Fed, the BoJ and the NB define their objective in terms of a single number: 2 per cent. The BoE is classified as having a point target, although the formulation of its objective is more complex and can be described as a "point with triggers". If the target is missed by more than ±1 pp, the Governor has to explain to the Chancellor the strategy towards returning inflation to the target after consideration of the trade-off involved. The remit indicates, however, that the ±1pp thresholds do not define a range target but are there for accountability.

Central banks with range targets - The RBA aims at an inflation range that is "*2-3% on average, over time*". It does not prefer any point within this range, which can then be interpreted as a zone of indifference. However, clarifications were provided over time: on its website, the RBA specifies that

[14] See Samarina and Apokoritis (2020) and Apel and Claussen (2017).
[15] The same flexibility could be gained by aiming at a point target and adopting a medium-term orientation in the conduct of monetary policy.

"*The inflation target is defined as a medium-term average rather than as a rate (or band of rates) that must be held at all times. This formulation allows for the inevitable uncertainties that are involved in forecasting, and lags in the effects of monetary policy on the economy*". In 2018, during a conference on the occasion of the 25 years of IT in Australia, the deputy Governor said that "*the inflation target can be thought of as a 'thick point'*" and that it "*doesn't mean that inflation with a '2' in front of it implies a zone of policy inaction. It simply acknowledges that inflation will obviously vary through time and that there is not much to be gained from being too precise*" (Debelle, 2018). The SNB does not indicate the 0-2% range of inflation explicitly, but uses the following formulation: "*equates price stability with a rise in the Swiss consumer price index (CPI) of less than 2% per annum. Deflation, i.e. a protracted decline in the price level, is also regarded as a breach of the objective of price stability*." The BoI has a price stability range target that is "*between 1 percent and 3 percent a year*".

Central banks with both focal point and range/bands - In this group, the variety of nuances in the formulation of the price stability is wider. The RBNZ aims "*to keep inflation between 1 and 3 percent on average over the medium term, with a focus on keeping future average inflation near the 2 percent target midpoint*". This formulation seems to be the legacy of the RBNZ having targeted a range since the beginning of the 1990s and only recently adding the 2% mid-point (see below for more details on the history of their inflation targets). The BoC and the CNB focus their attention on the mid-point (or focal point) and then specify the bands around it, which they call with different wording. The BoC defines them as a "control range" (it aims at "*keeping inflation, as measured by the total consumer price index (CPI), at 2 percent, with a control range of 1 to 3 per cent around this target*."); the CNB instead call them "tolerance bands" ("*an inflation target of 2% with a tolerance band of one percentage point in either direction*"). The SR indicates that "*The target is to hold inflation around 2 per cent a year*". But then adds that it "*uses a variation band of 1–3 per cent for the outcomes for CPIF* [(the CPI with a fixed interest rate)] *inflation, to illustrate the fact that monetary policy is not able to steer inflation in detail*." The variation band is intended to show that inflation fluctuates around the target and will not be exactly 2 per cent every single month and the SR clarifies that "*the objective of monetary policy is still that inflation shall be 2 per cent, the variation band of 1–3 per cent is not what is known as a target interval."*[16]

[16] See the Inflation Target section of the Sveriges Riksbank website https://www.riksbank.se/en-gb/monetary-policy/the-inflationtarget. "*The variation band does not affect the formulation of monetary policy, but is only to illustrate the fact that inflation normally varies. The Riksbank always aims for 2 per cent inflation, regardless of whether inflation is initially inside or outside the variation band.*"

Looking at the evolution of the formulation of the objectives over time and of the role of bands and ranges, there has been a tendency to specify a focal point within the range or the bands and/or to narrow the width of the bands. Communication efforts by several central banks have been devoted to clarify that the bands are not an inaction region or tolerance zone.

Most central banks that adopted IT during the 90s with the objective of providing a nominal anchor and "as a pragmatic response to the failure of other monetary policy regimes" in controlling inflation, decided for formulating their objectives in terms of ranges or, so called, control bands (Hammond, 2012). Over time, the objectives that were expressed as ranges or tolerance regions have been changed to or interpreted as having less hard edges than initially. The communication has been enhanced over time to strengthen the role of the mid-point. Central banks that adopted an explicit numerical target in the last decade decided for a point target (Fed and BoJ, both in 2012).

The RBNZ is an interesting example of these trends. It was the first central bank to adopt an IT framework in 1990. Its monetary policy objectives were outlined in a Policy Targets Agreement (PTA) with the Minister of Finance. The first PTA signed in 1990 defined price stability as an inflation rate between 0 and 2 per cent. This initial objective was replaced with a goal of 0 to 3 percent inflation in 1996, with the intent of allowing for more flexibility in managing tradeoffs. In 2002, the target was narrowed to 1 to 3 percent inflation over the medium term. Finally, in 2012 an explicit focus was given to the 2 percent mid-point of the 1 to 3 percent range. The RBNZ clarified that "*By enshrining the Reserve Bank's practice as point-targeting 2 percent inflation, it safeguarded against the risk of inflation expectations gravitating to 1 or 3 percent in the future*."[17]

The SR is another example. It adopted IT in 1993, announcing an inflation target of "*2%, with a tolerance level of +/- 1 percentage point*". In the words of the SR, "*the tolerance interval was to make it clear that deviations from the inflation target were probable, and that the Riksbank's aim was to try to limit these deviations*". Later on in May 2010, the SR decided to remove the tolerance interval of +/-1 percentage point from its specified inflation target. The SR justified this decision as follows: "*one can conclude that the tolerance interval has become obsolete: there is considerable understanding for the fact that inflation commonly deviates from the target and that the deviations are sometimes larger than 1 percentage point.*"[18] As of September 2017, when the SR changed the target variable for monetary policy from CPI to CPI with fixed interest rate, it started to use "variation

[17] See the History of Policy Target Agreements:
https://www.rbnz.govt.nz/monetary-policy/history-of-policy-targetsagreements
[18] See the 2010 Memorandum "The Riksbank removes the tolerance interval from its specified monetary policy target"
http://archive.riksbank.se/Upload/Dokument_riksbank/Kat_publicerat/Pressmeddelanden/2010/nr27e_beslutsunderlag.pdf

bands" to illustrate in a simple way that monetary policy's capacity to steer inflation in detail is very limited and that inflation normally varies around the inflation target.[19]

An interesting example is also the one of BoE, which, prior to 2000, had targeted ranges instead of a point. In 1992, the Chancellor announced a range target for inflation of 1-4% on RPIX inflation. In 1995, the target was changed to "*2.5% or less*". Finally, in 1997, when the MPC was set up and given the operational responsibility for formulating the UK's monetary policy, the current point target was chosen.

The last one that changed and narrowed the formulation of its target is the ECB. In 1998, it defined price stability in terms of a range ("*increase in the HICP of below 2%*"); in 2003 it provided a focal point within that range ("*an inflation aim of below, but close to, 2%*"). Finally in 2021 it opted for a point target.

3. Model-based analysis

In this section, we evaluate the macroeconomic stabilization properties of alternative monetary policy strategies under the assumption that the ELB constrains the policy rate. We simulate a standard New Keynesian model à la Smets and Wouters (2003), calibrated at quarterly frequency to the euro area economy.

The model features nominal wage and price stickiness and indexation to both previous-period inflation and the central bank inflation target, consumption habit, and adjustment costs on investment in physical capital. The different strategies are modeled by changing the monetary policy rule followed by the central bank.[20] An aggregate demand (risk premium) shock and an aggregate supply (price mark-up) shock feed the model. The steady-state annualized natural real rate is set to 0.5% and the inflation target to 2.0%. Thus, the policy rate in steady state is equal to 2.5%. We set the ELB at 0%. Households' and firms' expectations are model-consistent, in line with a large part of the literature.[21] The only exception is that in all simulations it is assumed that households and firms anticipate an ELB duration equal at most to three quarters (including the current one).[22] Busetti et al.,

[19] "The variation band, which stretches between 1 and 3 per cent, captures approximately three quarters of outcomes for CPIF inflation since mid-1995." See Sveriges Riksbank (2017).
[20] See the Appendix for a detailed exposition of the simulations.
[21] See Evans (2021) on the role of rational expectations and other assumptions commonly shared by a large part of the literature on model-based analysis of monetary policy, and the role of model prescriptions for the actual implementation of monetary policy.
[22] This assumption is made for computational reasons and to avoid implausibly large effects associated with the anticipation effect that typically characterizes perfect-foresight solutions of New Keynesian models. In a similar vein,

(2021) evaluate the performance of alternative makeup strategies in a similar environment, but allow the ELB duration to be fully endogenously determined. Moreover, they study both the case of fully rational, model-consistent expectations and the case of "hybrid" inflation expectations, i.e. a weighted average of adaptive (backward looking) and rational expectations. Our results are in line with theirs.

Our analysis does not take into account non-standard monetary policy instruments such as large scale asset purchases by the central bank, which can alleviate to some extent the constraints imposed by the ELB (Burlon et al., 2018 and Debortoli et al., 2019).

The section is organized as follows: section 3.1 simulates IT under alternative levels of the inflation target; section 3.2 evaluates ranges for the inflation target, and in particular the role of the perceived ceiling for inflation dynamics; section 3.3 assesses makeup strategies, i.e., PLT, AIT, and TPLT; finally, section 3.4 considers asymmetric monetary policy rules.

3.1 Inflation targeting with different levels of the inflation target

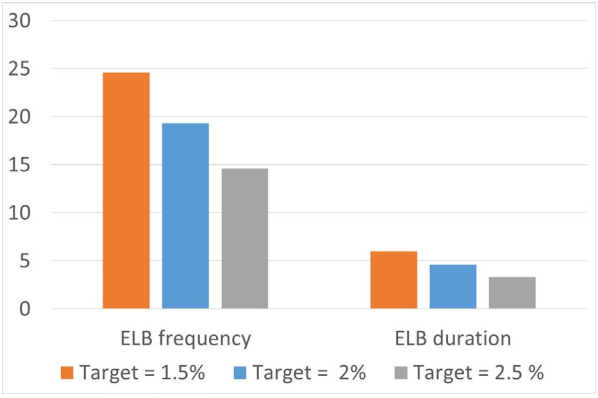
Section 2 indicated that all the surveyed central banks target a small and positive inflation rate, which in most cases is set around 2%. Recent literature finds that the optimal level of inflation is small and positive when the standard New Keynesian model accounts for firms' heterogeneity and systematic firm-level productivity trends (Adam and Weber, 2019), financial frictions (Abo-Zaid, 2015), the presence of long-lived ELB episodes (Dordal-i-Carreras et al., 2016) or a low equilibrium real rate of interest (Andrade et al., 2019). In this section we analyze the central bank's ability to achieve different targets and to stabilize inflation and output.

Figure 1 shows the results for the IT regime under alternative inflation targets, namely 1.5 and 2.5% against a benchmark case of a 2% inflation target. In the benchmark, inflation is on average lower than the target, because the central bank, in presence of the ELB, cannot reduce the policy rate by the amount needed to stabilize inflation dynamics when facing disinflationary shocks.

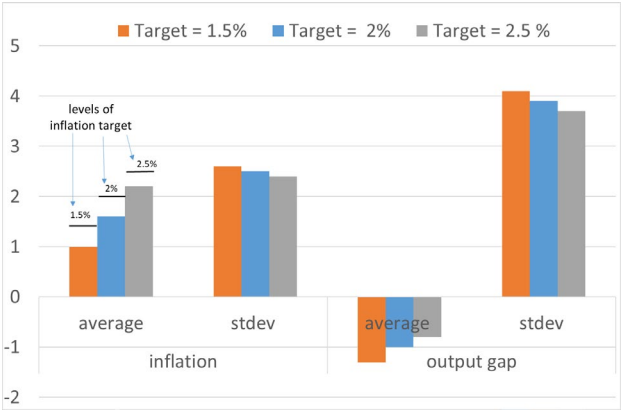
Kiley and Roberts (2017) include an emergency fiscal stimulus package that is enacted when the output gap is lower than -10 percent, which prevents the manifestation of extremely adverse outcomes, especially those related to the large amplification effects that characterize DSGE models once the ELB binds.

Figure 1 – Macroeconomic stabilization under different levels of inflation target

Panel A- ELB incidence



Panel B - inflation and output gap



Note: ELB frequency in %; ELB duration in quarters. For inflation: annual percentage point deviations from steady state; for the output gap: quarterly % deviations of output from its steady-state level. The statistics are derived from stochastic simulations around the model's non-stochastic steady state with an equilibrium real interest rate set equal to 0.5%. They are carried out for alternative levels of the inflation target taking into account an ELB constraint set equal to 0%.

The ability to achieve the target and stabilize inflation and output markedly deteriorates if the target is set at 1.5%, as the space for the central bank to decrease the policy rate in response to disinflationary shocks is reduced, given the ELB. Households anticipate it and decrease aggregate demand inducing firms to reduce output and inflation. As a result, the volatility of inflation, measured by its standard deviation, increases, average inflation is 1.0%, and the disinflationary bias is larger than under the 2.0% aim. The opposite result holds if the target is 2.5%, as the central bank is able to reduce to a larger extent the policy rate in response to the very same disinflationary shocks, which brings inflation on average broadly more in line with the target, and mitigates its volatility. ELB episodes are less frequent and their duration shorter. Increasing the target can however have some drawbacks, and the associated lower probability of hitting the ELB must be weighed against the costs of higher inflation, for example in terms of price dispersion and inefficient resource allocation; higher trend inflation is associated with a more volatile and unstable economy (Andrade et al., 2020; Ascari and Sbordone, 2014; Ascari and Ropele, 2009).

3.2 Ranges for the inflation target: the role of the perceived ceiling

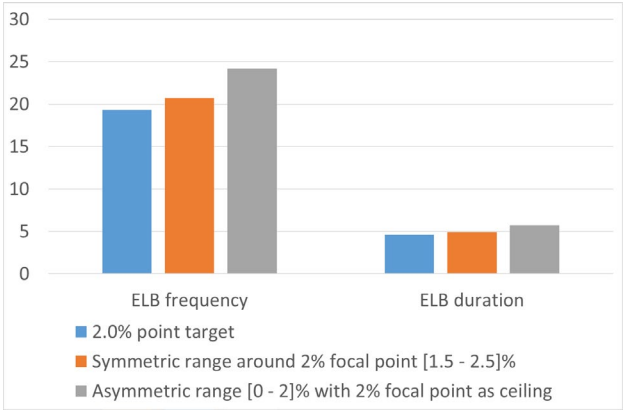
Figure 2 reports results for the case of a monetary policy strategy in which the inflation target is formulated as a range. We consider two cases: (*i*) a symmetric range; (*ii*) an asymmetric range in which the upper bound is perceived as a ceiling.

In the first case, the range is symmetric around a 2% focal point and its lower and upper bounds are 1.5 and 2.5, respectively. The range is not an "inaction region" because the central bank aims at the focal point. However, the reaction to inflation within and outside the range is different, as the central bank is more tolerant when inflation lies within the bands. We calibrate the (non-linear) rule so that the difference within and outside the bands is small, i.e. the bounds are "soft", consistently with the current practice among central banks that formulate their objectives using bands or ranges (Section 2.3).

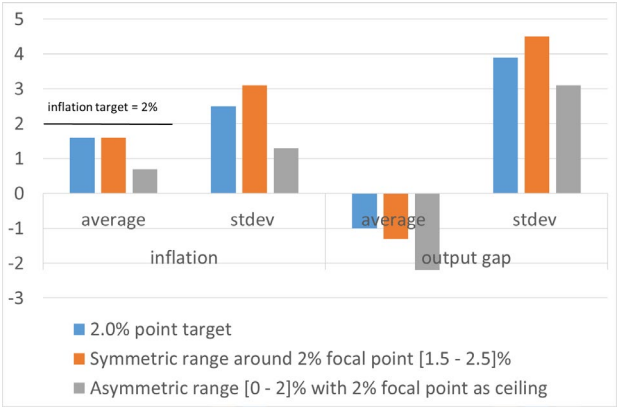
In the case of a symmetric range (1.5-2.5%) with 2% as focal point, inflation on average would be equal to the one under IT with a point target, and in both cases below the target of 2%. Inflation volatility would instead be higher. The smaller response of the central bank to inflation within the bands deteriorates the macroeconomic stabilisation. The output gap would be on average negative as in the benchmark case but higher in absolute terms. Similarly, the output gap volatility, the ELB frequency and duration would increase.

Figure 2 – Macroeconomic stabilization under different formulation of inflation target

Panel A - ELB incidence



Panel B - inflation and output gap



Note: ELB frequency in %; ELB duration in quarters. For inflation: annual percentage point deviations from steady state; for the output gap: quarterly % deviations of output from its steady-state level. The statistics are derived from stochastic simulations around the model's non-stochastic steady state with an equilibrium real interest rate set equal to 0.5%. They are carried out for alternative specifications of the interest-rate rule taking into account an ELB constraint set equal to 0%.

In the case of an asymmetric range with a ceiling at 2%, inflation is on average much lower than under IT while the volatility is lower. Similarly, both GDP mean and volatility are lower. Households and firms anticipate that the central bank strongly adjusts the policy rate to prevent deflation and above-target inflation (i.e. the range has "hard" bounds) and, thus, limit fluctuations in aggregate

demand, output, and inflation. At the same time, households and firms reduce on average consumption, investment, and prices, because they expect the central bank to set the policy rate at a higher level on average to avoid inflation above the 2% upper bound. Overall, the combination of the ELB and a tighter monetary policy yields too low inflation and output.

To sum up, a symmetric range around the 2% focal point with monetary policy reacting less aggressively when inflation is inside the bands improves upon an asymmetric range with the focal point located in its upper bound, but performs worse than an IT with point target.

3.3 Makeup strategies

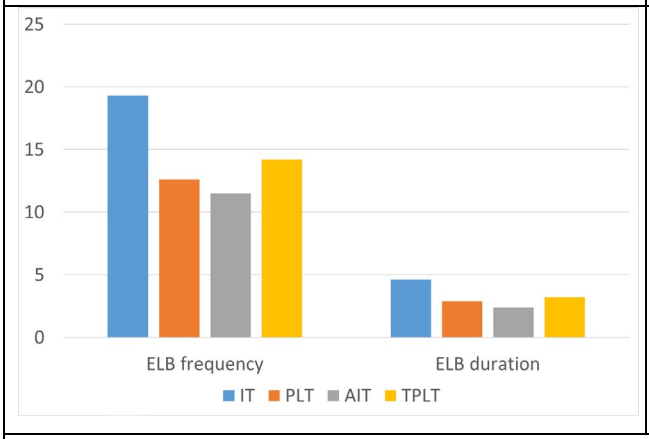
Previous simulations show that, when the natural rate is low and the ELB holds, a standard IT approach can lead to actual inflation being on average below target (disinflationary bias).

In this section, we evaluate the properties of a number of makeup strategies, PLT and AIT, with which the central bank systematically offsets past inflation shortfalls by engineering periods of above-target inflation. We also consider the case of TPLT, i.e., the price level substitutes the inflation term as a goal of the central bank when the economy is at the ELB (Bernanke et al., 2019).

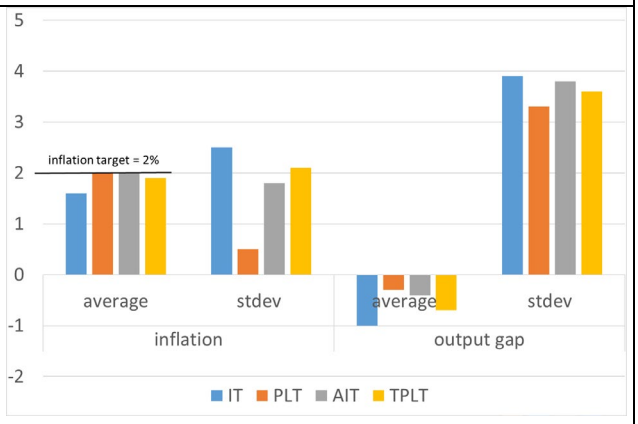
Figure 3 reports the outcomes of these alternative monetary policy strategies and compares the results with the benchmark case of an IT regime with a 2% target. The PLT regime provides the best performance in terms of inflation stabilization, followed by AIT and TPLT; IT is the worst performer. In the case of PLT, inflation has the lowest volatility and, on average, it is equal to the 2.0% target. Similar results hold for the output gap. The frequency and duration of the ELB are lower under PLT than under IT. Under PLT, in case of disinflationary shocks households and firms anticipate that the central bank will fully offset the past low inflation ("bygones are not bygones") to stabilize the price level. The anticipation of future higher inflation rates and lower policy rate reduces the expected real interest rate and, thus, stabilizes current aggregate demand and inflation, which consequently is, on average, on target. The AIT regime has the second best performance. Inflation is de facto on target and is more stable than under IT. The ELB has the lowest frequency and shortest duration among all the makeup strategies. The central bank reacts to the average inflation rate computed over the past eight quarters (including the current one), whose value is likely to be low because of the ELB. If current inflation increases, the central bank raises the policy rate less than under IT. Similar to AIT, the TPLT regime performs worse than PLT but better than IT. Under this strategy, price level stabilization ("bygones are not bygones") becomes a goal only when the ELB is hit. This makes the TPLT regime more effective in stabilizing inflation than IT.

Figure 3– Macroeconomic stabilization under different makeup strategies

Panel A - ELB incidence



Panel B - inflation and output gap



Note: ELB frequency in %; ELB duration in quarters. For inflation: annual percentage point deviations from steady state; for the output gap: quarterly % deviations of output from its steady-state level. The statistics are derived from stochastic simulations around the model's non-stochastic steady state with an equilibrium real interest rate set equal to 0.5%. They are carried out for alternative specifications of the interest-rate rule taking into account an ELB constraint set equal to 0%. IT = inflation targeting; PLT = price level targeting; AIT = average inflation targeting; TPLT= temporary price level targeting.

The results reported above are based on (i) a mix of demand and supply shocks, with the former explaining a large share of GDP fluctuations, consistently with empirical evidence and (ii) model-consistent expectations.

As reported by Busetti et al., (2021), results under the assumption that the mix of shocks is rebalanced towards supply shocks, so that they explain a larger share of GDP volatility, show that PLT still provides the best performance. However, PLT is less successful in terms of GDP stabilization: to stabilize the price level after a supply shock, the central bank keeps the policy rate low when inflation is low and GDP is high (and, symmetrically, keeps the policy rate high when inflation is high and the GDP low). Thus, monetary policy becomes more pro-cyclical under PLT if supply shocks are the main drivers of business cycle fluctuations. Again, AIT and TPLT, which can be interpreted as a compromise between IT and PLT, have performances whose effectiveness is between those of IT and PLT.

Busetti et al., (2021) also show that gains from the makeup strategies over an IT regime also rely on agents having model-consistent expectations, i.e. households and firms being forward-looking. This implies that households anticipate the future path of shocks and variables, in particular the policy rate and inflation, when taking current decisions. Under model-consistent expectations, disinflationary shocks, and PLT, agents anticipate that the central bank will allow high inflation to offset current low

inflation. Because current inflation depends on expected future inflation, under PLT current inflation increases as agents expect future inflation to increase as well. This stabilizes it around the target. Under adaptive, i.e. backward-looking, inflation expectations, the anticipation effect, which is key for PLT effectiveness, is less strong. Thus, expectations adjust in a more gradual way. The central bank still reduces inflation deviations from the target, but the total effect is weaker than with model-consistent expectations and, thus, the policy rate is kept at low levels for longer. The relative benefits of PLT over IT are less stark. Inflation still shows the lowest volatility under PLT than under the other strategies and, on average, inflation is equal to the target. The ELB frequency and duration is very close under both PLT and IT regimes. An AIT strategy yields a lower ELB frequency and shorter ELB episodes, relative to IT and PLT. Moreover, inflation is substantially on target and its volatility is lower than under IT, though at the cost of weaker output stabilization.

3.4 Asymmetric monetary policy rules

A central bank that wishes to achieve its inflation target in a low natural rate environment might want to design a strategy that corrects for the disinflationary bias. In the spirit of Bianchi et al., (2021), we explore the stabilization properties of a strategy that responds more aggressively to below-target inflation than to above-target inflation (Figure 4). We implement this strategy as an asymmetric interest rate rule, in which the sensitivity of the policy rate to inflation is higher (lower) if inflation is below (above) the target. This set of rules is not a makeup strategy as they do not require engineering a makeup for past deviations of inflation from target.[23]

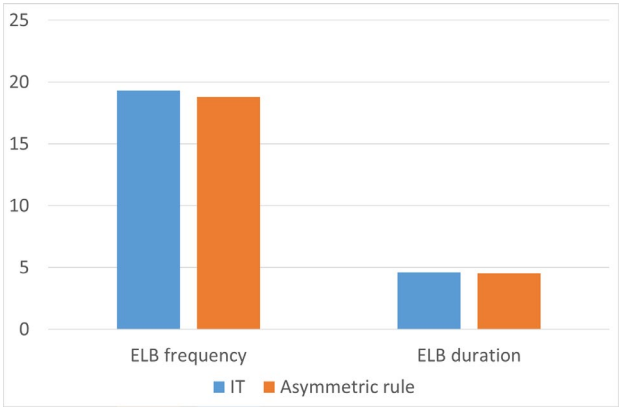
Within IT regimes, if the inflation coefficient in the Taylor rule is higher (lower) if inflation is below (above) target, the disinflationary bias disappears relatively to a symmetric IT strategy.[24] The central bank reacts more strongly to below-target inflation by reducing the policy rate to a larger extent; moreover, it raises the policy rate to a lower extent in the case of above-target inflation. Households and firms anticipate that on average the monetary policy stance is more expansionary and the policy rate lower and, thus, increase aggregate demand and economic activity. Inflation is stabilized around a higher level, correcting the bias arising from the presence of the ELB.

[23] Bianchi et al., (2021) point out that similar results to those obtained with an asymmetric rule of this kind can be obtained if the central bank implements an asymmetric target range around the inflation objective, with the lower bound of the range being closer to the objective. Maih et al., (2021) derive a similar rule as an optimal simple rule for the euro area in an environment with the ELB and a low natural rate.

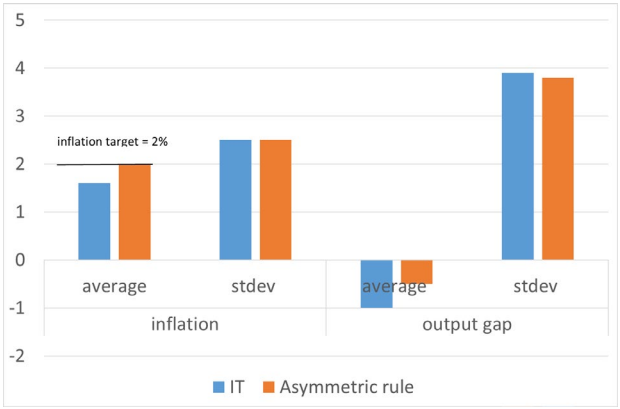
[24] The fact that the disinflationary bias disappears clearly depends on the magnitude of the inflation coefficient in the Taylor rule. In our simulations, when inflation is above (below) the target, we decrease (increase) the coefficient by 14% relative to the symmetric (standard IT) rule.

Figure 4 – Macroeconomic stabilization under symmetric and asymmetric strategies

Panel A - ELB incidence



Panel B - inflation and output gap



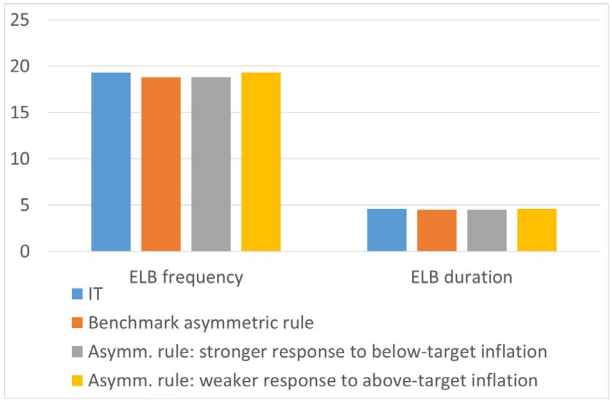
Note: ELB frequency in %; ELB duration in quarters. For inflation: annual percentage point deviations from steady state; for the output gap: quarterly % deviations of output from its steady-state level. The statistics are derived from stochastic simulations around the model's non-stochastic steady state with an equilibrium real interest rate set equal to 0.5%. They are carried out for alternative specifications of the interest-rate rule taking into account an ELB constraint set equal to 0%. IT = inflation targeting; Asymmetric rule = stronger response of the policy rate to below-target inflation than to above-target inflation.

In Figure 5 we also report results for the case of the central bank reacting less strongly to above-target deviations (and not more strongly to below-target deviations) or more forcefully to below-target deviations (and not less strongly to above-target deviations).[25] We find that the disinflationary bias is more pronounced than in the combined strategy. For lower response to above-target deviations, inflation volatility is higher, also with respect to the benchmark IT case, because the central bank is less aggressive in stabilizing above-target inflation. Nevertheless, a strategy which responds less aggressively to above-target inflation still reduces the disinflationary bias and could be helpful to bring back inflation towards its target when interest rates are close to their ELB.

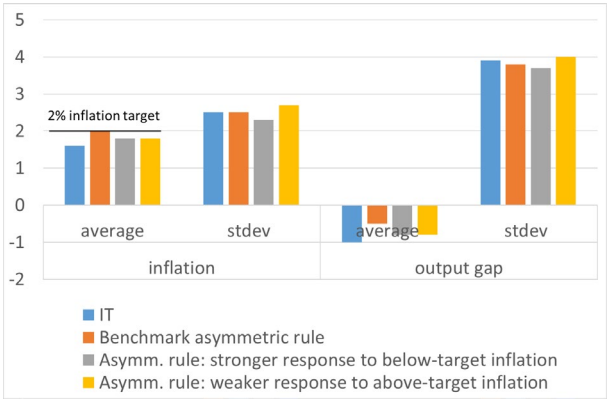
[25] The Taylor rule coefficient on inflation is set to the benchmark calibration if inflation is below or above target, respectively.

Figure 5 – Macroeconomic stabilization under different calibration of asymmetric strategies

Panel A - ELB incidence



Panel B - inflation and output gap



Note: ELB frequency in %; ELB duration in quarters. For inflation: annual percentage point deviations from steady state; for the output gap: quarterly % deviations of output from its steady-state level. The statistics are derived from stochastic simulations around the model's non-stochastic steady state with an equilibrium real interest rate set equal to 0.5%. They are carried out for alternative specifications of the interest-rate rule taking into account an ELB constraint set equal to 0%. IT = inflation targeting. Benchmark asymmetric rule: stronger response of the policy rate to below-target inflation than to above-target inflation.

4. Conclusions

In this paper, we have reviewed alternative monetary policy strategies in a low interest rate environment, according to the recent experience in advanced economies and to model-based simulations.

Our international review of the experience in advanced economies shows that central banks choose to target a small and positive inflation rate, which is typically 2%. A few central banks changed their target in recent years. In the low interest rate environment, several central banks have clarified the symmetry of their targets. Range targets and bands are more common among small open economies. Over time, central banks that changed the formulation of their target went in the direction of narrowing it, by either reducing the ranges or bands or by opting for a point target.

Our model-based results suggest that, in the presence of a non-negligible risk of reaching the ELB, an IT strategy can lead to a downward inflation bias. A point inflation target appears to outperform a target range, especially if the target is perceived as a ceiling. In a low interest rate environment, makeup strategies are more effective in stabilizing inflation and economic activity. Similarly, an asymmetric reaction function that responds more strongly to disinflationary than to

inflationary shocks can reduce the disinflationary bias in the long run. The model-based simulations results rely on some simplifying assumptions. First, we assume that the central bank is perfectly credible. Second, financial stability issues are not considered. Relaxing these assumptions is left for future research.

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Table 1 - An overview of the price stability objectives

Central bank	Target set by [1]	Price Index	Numerical inflation target / definition	Format	Horizon	History
Sveriges Riksbank (Sweden)	CB	CPIF (CPI with a fixed interest rate)	2%	Point, with variation band [2]	Not specified	Introduced in 1993 on CPI at 2% with a tolerance band of +/-1pp. In 2010 the interval was abolished. In September 2017 change of index to CPIF and variation bands reintroduced but with less emphasis on them
Reserve Bank of Australia (Australia)	CB and G	CPI	"2–3 per cent, on average, over time"	Range	Medium-term [3]	Introduced in 1993
Bank of Japan (Japan)	CB	CPI	2%	Point	"at the earliest possible time"	Before 2012: no numerical target. In February 2012: inflation goal "within a positive range of 2 percent or lower" and "1% for the time being". In January 2013: inflation target raised at 2%[4]
Swiss National Bank (Switzerland)	CB	CPI	0-2% [5]	Range	Medium-term specified as around three-years	-
Norges Bank (Norway)	G	CPI	2%	Point	Medium-term	Introduced in 2001, the numerical target was 2.5%. Changed in 2018 to 2%[6]
Bank of Israel (Israel)	G and CB	CPI	1-3%	Range	Within 2 years[7]	-
Czech National Bank (Czech Republic)	CB	CPI	2%	Point (with 1pp tolerance band)[8]	Medium-term	Numerical target adopted in 2001 From 2006 to 2010 target was 3% with a 1pp tolerance band From January 2010 2% target
Reserve Bank of New Zealand (New Zealand)	G	CPI	1-3 % with 2% mid-point	Range with focal point	Medium-term	Inflation targeting adopted in 1990: inflation target defined as a band of 0-2%; in 1996 band changed to 0-3%; in 2002 to 1-3%; in 2012 the inflation target was retained at 1-3% but with a focus on a 2% mid-point[9]
Bank of England (United Kingdom)	G	CPI	2%	Point with triggers [10]	Applies at all times; each time inflation deviates by ±1pp the Bank has to indicate an appropriate horizon to return inflation to the target	From 1997 – 2003 the target was based on the Retail Prices Index excluding mortgage interest payments (RPIX) and it was 2.5% In 2003 reduced to 2% on CPI
Bank of Canada (Canada)	G and CB	CPI	2% with a control range of 1-3%	Point with control range	six to eight quarters, on average	Reviewed every 5 years. In 2016 they reviewed the level and the measure of inflation in the target without changing them
Federal Reserve System (United States)	CB	PCE	2%	Point	Over the longer run	Numerical target first specified in January 2012. Previously, there was no explicit target[11]
European Central Bank (Euro Area)	CB	HICP	2%	Point	Over the medium term	In 1998 price stability was defined as year-on-year increase of inflation of below 2%, in 2003 aim clarified as "below, but close to, 2%", in 2021 the 2% symmetric point target was chosen

Source: central bank websites.

(1) G = Government; CB = Central bank.

(2) "the Riksbank uses a variation band of 1–3 per cent for the outcomes for CPIF inflation, to illustrate the fact that monetary policy is not able to steer inflation in detail. The variation band is intended to show that inflation varies around the target and will not be exactly 2 per cent every single month. However, the objective of monetary policy is still that inflation shall be 2 per cent, the variation band of 1–3 per cent is not what is known as a target interval."

(3) "The inflation target is defined as a medium-term average rather than as a rate (or band of rates) that must be held at all times. This formulation allows for the inevitable uncertainties that are involved in forecasting, and lags in the effects of monetary policy on the economy. Experience in Australia and elsewhere has shown that inflation is difficult to fine-tune within a narrow band. The inflation target is also, necessarily, forward-looking."

(4) From 2006 and 2011, the BoJ reported info on the range and mid-point of the inflation rates that members of the Policy board deemed as consistent with price stability. The range was between 0 and 2% with 1% mid-point.

(5) "The SNB equates price stability with a rise in the Swiss consumer price index (CPI) of less than 2% per annum. Deflation, i.e. a protracted decline in the price level, is also regarded as a breach of the objective of price stability."

(6) "In 2001, when inflation targeting was introduced, the Norwegian economy was in a situation where increasing oil revenues would gradually be phased into the economy. At the time, the numerical target was set at 2.5 percent. The reasoning was that an expected real appreciation could then occur partly in the form of wider price and cost differentials between Norway and its trading partners. The period of rising oil revenue spending now appears largely to be over."

(7) "Within two years at most"

(8) "The inflation target is defined as annual consumer price index growth of 2%. The CNB will strive to ensure that actual inflation does not differ from the target by more than one percentage point on either side."

(9) The Policy Targets Agreement of 2017 introduced maximum sustainable employment as a higher-order objective by the Minister of Finance. Later, an amendment to the Reserve Bank Act in 2018 gave maximum sustainable employment equal status as a primary objective with price stability, thereby formally giving monetary policy in New Zealand a dual-mandate.

(10) "The Bank is liable at all times, has to report to the Government is target is missed by more than 1pp either side."

(11) From around 2000 until the Great Recession, the general consensus among FOMC participants that their inflation target should be about 1.5. By the end of the recession in 2009, however, the consensus had shifted up to 2%, which became the official target announced to the public in January 2012 (Shapiro, Wilson 2019).

Appendix - Technical features of the model and the monetary policy rules

This Appendix offers a detailed overview of some technical features of the model and the implementations of the different strategies.

The model. We simulate a standard New Keynesian model à la Smets and Wouters calibrated at quarterly frequency to the euro area economy.[26] Our simulated and theoretical volatilities are similar and in line with those of the ECB DSGE model NAWM II. The theoretical volatility of real GDP quarterly growth is 1.0 (0.6 in the data), the theoretical quarterly inflation volatility is 0.6 (0.4 in the data).[27] The shocks are calibrated to match the observed volatilities of output and inflation over the 1985-2014 period under the assumptions of IT and no-ELB. Moreover, the calibration is such that the demand shock explains around 80% of both real GDP growth and inflation volatility, which is broadly in line with the empirical evidence. For each reported monetary policy rule, we run 1000 simulations. Each simulation lasts 200 quarters. In every quarter, households and firms are surprised by a new shock realization. The first 100 periods are discarded (burn-in sample). Thus, reported model-based means and volatilities are cross-simulation averages, based on the last 100 quarters of each simulation.

The ELB is implemented by shocks to the monetary policy rule: if in a given period the ELB is violated (i.e., the policy rate is below zero) a restrictive monetary policy shock restores it by forcing the policy rate to be equal to zero in that period. It is assumed that households and firms anticipate an ELB duration equal at most to three quarters (including the current one).

Monetary policy rules. For the definition of the regimes and the calibration, we follow the heuristics for the euro area. The rule for inflation targeting, our benchmark, is

$$\frac{R_t}{\bar{R}} = \left(\frac{R_{t-1}}{\bar{R}}\right)^{\rho_R} \left(\frac{\pi_t}{\bar{\pi}}\right)^{(1-\rho_R)\rho_\pi} \left(\frac{y_t}{y_{t-1}}\right)^{(1-\rho_R)\rho_y},$$

where $\bar{R}$ is the gross steady-state policy rate, $\bar{\pi}$ the gross inflation rate target, and y_t the output level. The parameters ρ_R, ρ_π, ρ_y are set to 0.867, 1.9, and 0.15, respectively, throughout all simulations. The value for the inflation target in net annualized terms is 2% for all rules, unless otherwise specified. To assess the impact of the level of the inflation target, in the simulations of Section 3 we also consider inflation target levels at 1.5% and 2.5%.

The rule for the symmetric range target is

$$\frac{R_t}{\bar{R}} = \left(\frac{R_{t-1}}{\bar{R}}\right)^{\rho_R} \left(\frac{\pi_t}{\bar{\pi}}\right)^{(1-\rho_R)\rho_\pi} \left(\min\left(\frac{\pi_t}{\bar{\pi} - 0.5/400}, 1\right)\right)^{(1-\rho_R)\rho_{\pi O}} \left(\max\left(\frac{\pi_t}{\bar{\pi} + 0.5/400}, 1\right)\right)^{(1-\rho_R)\rho_{\pi O}} \left(\frac{y_t}{y_{t-1}}\right)^{(1-\rho_R)\rho_y}$$

where the coefficient ρ_π is set to 1.3 (instead of 1.9 as in the other reported simulations) and the coefficient $\rho_{\pi O}$ to 0.38. The asymmetric monetary policy rule for the asymmetric range in which the upper bound is perceived as a ceiling is

$$\frac{R_t}{\bar{R}} = \left(\frac{R_{t-1}}{\bar{R}}\right)^{\rho_R} \left(\frac{\pi_t}{\bar{\pi}}\right)^{(1-\rho_R)\rho_\pi} \left(\min\left(\frac{\pi_t}{\bar{\pi} - 1.999/400}, 1\right)\right)^{20(1-\rho_R)\rho_\pi} \left(\max\left(\frac{\pi_t}{\bar{\pi}}, 1\right)\right)^{20(1-\rho_R)\rho_\pi} \left(\frac{y_t}{y_{t-1}}\right)^{(1-\rho_R)\rho_y},$$

[26] See Smets and Wouters (2003).

[27] See Table 7 in Coenen et al., (2018, revised December 2019).

where the coefficient ρ_π is set back to 1.9. Note that the central bank response when inflation is outside the bounds is 20 times larger than in the previous rule.

The PLT and AIT monetary policy rules are respectively

$$\frac{R_t}{\bar{R}} = \left(\frac{R_{t-1}}{\bar{R}}\right)^{\rho_R} \left(\frac{p_t}{\bar{p}}\right)^{(1-\rho_R)\rho_\pi} \left(\frac{y_t}{y_{t-1}}\right)^{(1-\rho_R)\rho_y}$$

and

$$\frac{R_t}{\bar{R}} = \left(\frac{R_{t-1}}{\bar{R}}\right)^{\rho_R} \left(\prod_{s=0}^{7} \left(\frac{\pi_{t-s}}{\bar{\pi}}\right)\right)^{\frac{1}{8}(1-\rho_R)\rho_\pi} \left(\frac{y_t}{y_{t-1}}\right)^{(1-\rho_R)\rho_y},$$

where the terms p_t and $\bar{p}$ are the price level in period *t* and its steady-state value, respectively, and the term $\left(\prod_{s=0}^{7} \left(\frac{\pi_{t-s}}{\bar{\pi}}\right)\right)^{\frac{1}{8}}$ is the average (gross) inflation rate, as a deviation from the target, over the most recent eight quarters. The price level is defined as the product of past inflation rates: $(\prod_{s=0}^{t} \pi_{t-s})$. The TPLT rule is such that the price level substitutes the inflation term in the IT rule when the economy is at the ELB.

Finally, the asymmetric rule with both (above- and below-target inflation) asymmetric responses is

$$\frac{R_t}{\bar{R}} = \left(\frac{R_{t-1}}{\bar{R}}\right)^{\rho_R} \left(\frac{\pi_t}{\bar{\pi}}\right)^{(1-\rho_R)\rho_\pi} \left(\max\left(\frac{\pi_t}{\bar{\pi}}, 1\right)\right)^{-0.14(1-\rho_R)\rho_\pi} \left(\min\left(\frac{\pi_t}{\bar{\pi}}, 1\right)\right)^{0.14(1-\rho_R)\rho_\pi} \left(\frac{y_t}{y_{t-1}}\right)^{(1-\rho_R)\rho_y}.$$

The rules with lower response to above-target inflation and higher response to below-target inflation are

$$\frac{R_t}{\bar{R}} = \left(\frac{R_{t-1}}{\bar{R}}\right)^{\rho_R} \left(\frac{\pi_t}{\bar{\pi}}\right)^{(1-\rho_R)\rho_\pi} \left(\max\left(\frac{\pi_t}{\bar{\pi}}, 1\right)\right)^{-0.14(1-\rho_R)\rho_\pi} \left(\frac{y_t}{y_{t-1}}\right)^{(1-\rho_R)\rho_y}$$

and

$$\frac{R_t}{\bar{R}} = \left(\frac{R_{t-1}}{\bar{R}}\right)^{\rho_R} \left(\frac{\pi_t}{\bar{\pi}}\right)^{(1-\rho_R)\rho_\pi} \left(min\left(\frac{\pi_t}{\bar{\pi}}, 1\right)\right)^{0.14(1-\rho_R)\rho_\pi} \left(\frac{y_t}{y_{t-1}}\right)^{(1-\rho_R)\rho_y},$$

respectively.