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A comparison of monetary policy rules in an estimated TANK model

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Rafael Gerke
Sebastian Giesen
Daniel Kienzler
Joost Röttger
Alexander Scheer

Deutsche Bundesbank, Wilhelm-Epstein-Straße 14, 60431 Frankfurt am Main,
Postfach 10 06 02, 60006 Frankfurt am Main

Tel +49 69 9566-0

Please address all orders in writing to: Deutsche Bundesbank,
Press and Public Relations Division, at the above address or via fax +49 69 9566-3077

Internet http://www.bundesbank.de

Non-technical summary

An article in a recent issue of the Deutsche Bundesbank's Monthly Report (Deutsche Bundesbank, 2021) surveys the main insights from the Eurosystem's 2020-21 monetary policy strategy review. One of the topics covered by this review was the potential offered by history-dependent and asymmetric monetary policy strategies to address limitations faced by conventional monetary policy due to an effective lower bound (ELB) on the short-term nominal interest rate. This paper presents a model-based assessment of history-dependent and asymmetric monetary policy strategies. It provides the details on the model used for these analyses, the parametrisation and the simulation method.

The simulations reveal a sizeable negative inflation bias for conventional monetary policy due to the ELB. The lower the equilibrium real interest rate or the lower the inflation target, the greater the likelihood of hitting the ELB, i.e. of interest rates becoming constrained from below.

As discussed in Deutsche Bundesbank (2021) and shown here in more detail, history-dependent and asymmetric monetary policy strategies allow the limitations induced by the ELB to be addressed. This result is derived under the assumption that such strategies are credible and well understood by the agents in the economy. The analysis does not, however, incorporate or discuss the potential outcome when those assumptions are not met.

There are two main results with respect to the comparison of alternative monetary policy strategies. First, history-dependent strategies can reduce or even eliminate the negative inflation bias induced by the ELB. This is due to an automatic stabilising effect on market expectations. The higher the degree of history dependence, the more it reduces the negative inflation bias. Second, asymmetric strategies can also reduce the negative inflation bias. Specifically, through a more forceful monetary expansion when the inflation rate is below target (compared to above target), an asymmetric strategy allows the negative inflation bias induced by the ELB to be mitigated.

With respect to an asymmetric strategy, the simulations reveal that its specific design matters for achieving the effects desired by monetary policy. For example, a combination of history-dependent and asymmetric strategies, like asymmetric average inflation targeting, can reduce the ELB frequency compared to conventional monetary policy. However, it might also lead to a positive inflation bias. The paper illustrates possible ways to fine-tune an asymmetric strategy to achieve certain objectives, like minimising the inflation bias or inflation volatility.

Nichttechnische Zusammenfassung

Ein Artikel in einem kürzlich erschienenen Monatsbericht der Deutschen Bundesbank (Deutsche Bundesbank, 2021) gibt einen Überblick über die wichtigsten Erkenntnisse aus der Überprüfung der geldpolitischen Strategie des Eurosystems. Zu den Themenfeldern der Überprüfung gehörten u.a. die Analyse alternativer geldpolitischer Strategien, mit deren Hilfe potenziell die Einschränkungen konventioneller Geldpolitik an der effektiven Zinsuntergrenze (ZUG) abgeschwächt werden könnten. In diesem technischen Papier wird eine modellbasierte Untersuchung vergangenheitsabhängiger und asymmetrischer Strategien vorgestellt. Es enthält Details zum verwendeten Modell, der unterstellten Parametrisierung des Modells und der Simulationsmethode.

Die durchgeführten Simulationen lassen erkennen, dass eine konventionelle Inflationssteuerung aufgrund der ZUG mit einer erheblichen negativen Inflationsverzerrung einhergeht. Je niedriger der gleichgewichtige Realzinssatz oder je niedriger das Inflationsziel, desto höher die Wahrscheinlichkeit, die ZUG zu erreichen.

Wie Deutsche Bundesbank (2021) illustriert und hier ausführlich dargestellt wird, ermöglichen vergangenheitsabhängige oder asymmetrische geldpolitische Strategien, die Beschränkungen der ZUG abzumildern. Dieses Ergebnis wird unter der Annahme abgeleitet, dass die jeweilige geldpolitische Strategie glaubwürdig und von den Akteuren verstanden werden. Die Analyse berücksichtigt und diskutiert jedoch nicht die potenziellen Auswirkungen, wenn von diesen Annahmen abgewichen wird.

Hinsichtlich des Vergleichs der alternativen Strategien kommt dieses Papier zu zwei wesentlichen Ergebnissen. Erstens können vergangenheitsabhängige Strategien die durch die ZUG induzierte negative Inflationsverzerrung abmildern. Dies ist auf einen automatischen Stabilisierungseffekt der Markterwartungen zurückzuführen. Entsprechend reduziert eine stärkere Vergangenheitsabhängigkeit die negative Inflationsverzerrung. Zweitens können asymmetrische Strategien ebenso die negative Inflationsverzerrung reduzieren. Insbesondere wenn die Inflationsrate unter dem Zielwert liegt, ermöglicht eine kräftigere geldpolitische Reaktion (im Vergleich zu einer Abweichung über dem Zielwert), die durch die ZUG induzierte Inflationsverzerrung abzuschwächen.

Die Simulationen zu den asymmetrischen Strategien zeigen, dass deren spezifische Ausgestaltung wichtig ist, um die geldpolitisch gewünschten Effekte zu erzielen. So kann beispielsweise eine Kombination aus vergangenheitsabhängigen und asymmetrischen Strategien, wie einem asymmetrischen Inflationszielsteuerung, die Häufigkeit der ZUG im Vergleich zu einer konventionellen Inflationssteuerung reduzieren. Gleichzeitig könnte diese jedoch auch zu einer positiven Inflationsverzerrung führen. Das Papier veranschaulicht mögliche Wege zur spezifischen Ausgestaltung einer asymmetrischen Strategie, um bestimmte Ziele zu erreichen, wie zum Beispiel die Minimierung der Inflationsverzerrung oder der Inflationsvolatilität.

A comparison of monetary policy rules in an estimated TANK model*

Rafael Gerke Sebastian Giesen Daniel Kienzler
Joost Röttger Alexander Scheer

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Abstract

We compare the stabilisation properties of history-dependent and asymmetric interest rate rules, taking into account the constraint posed by the effective lower bound on nominal interest rates. Specifically, we use a medium-scale Two-Agent New Keynesian (TANK) model that was estimated on euro area data. Our simulation results suggest that under rational expectations history-dependent rules can attenuate or even undo the sizeable negative inflation bias that we observe under standard inflation targeting. They can also better stabilise inflation, but output becomes more volatile. Asymmetric rules furthermore reduce the negative inflation bias. However, the reduction in inflation volatility is less pronounced compared to history-dependent rules. We further show that an appropriate calibration of an asymmetric inflation targeting rule improves its performance along specific dimensions.

Keywords: Monetary policy, effective lower bound, inflation target, make-up strategies, asymmetric policy rules
JEL Classification: E31, E52, E58

*Rafael Gerke (e-mail: rafael.gerke@bundesbank.de), Sebastian Giesen (e-mail: sebastian.giesen@bundesbank.de), Daniel Kienzler (e-mail: daniel.kienzler@bundesbank.de), Joost Röttger (e-mail: joost.roettger@bundesbank.de), Alexander Scheer (e-mail: alexander.scheer@bundesbank.de): Deutsche Bundesbank, Monetary Policy and Analysis Division, Wilhelm-Epstein-Straße 14, 60431 Frankfurt, Germany. An earlier version of this paper circulated under the title "Effective lower bound and make-up strategies". The views expressed in this paper are those of the authors and do not necessarily reflect those of the Deutsche Bundesbank or the Eurosystem.

1 Introduction

Since 2008, the Eurosystem has repeatedly cut its policy rates to counteract the impact of the financial and sovereign debt crises. However, during 2014, the scope for further cuts was increasingly exhausted, and the effective lower bound (ELB) on interest rates became an ever more binding constraint for the Eurosystem. In response, the Eurosystem implemented a series of then new unconventional policy measures with the aim of achieving a more accommodative monetary policy stance. While these policies helped mitigate the challenges posed by the ELB, they may also imply undesirable side effects.[1]

As illustrated in Deutsche Bundesbank (2021) and analysed here in more detail, history-dependent and asymmetric monetary policy strategies allow the challenges induced by the ELB to be addressed as well, in particular the negative inflation bias.[2] History-dependent strategies, like average inflation targeting or price level targeting, use the expectation channel as an automatic stabiliser: If the (average) inflation rate is below the central bank's target, forward-looking agents in the economy expect (automatically) a more expansionary monetary policy until the inflation rate reaches its target. This means that monetary policy intentionally aims at overshooting the inflation target temporarily.

An asymmetric monetary policy strategy is another possibility in which the limitations imposed by the ELB be mitigated. In the case that we discuss in the paper, monetary policy reacts more strongly to negative than to positive deviations of the inflation rate from its target. Thereby, it can raise the average

[1]See e.g. Altavilla, Lemke, Linzert, Tapking and von Landesberger (2021) for an overview on the efficacy, effectiveness and potential side effects of unconventional monetary policies in the euro area. For potential side effects related to fiscal policy, see Work stream on monetary-fiscal policy interactions (2021).

[2]See e.g. Coenen, Montes-Galdon and Schmidt (2021), Bianchi, Melosi and Rottner (2021), Arias, Bodenstein, Chung, Drautzburg and Raffo (2020), Mertens and Williams (2019) and Bernanke, Kiley and Roberts (2019) for a recent treatment of history-dependent and asymmetric monetary policy strategies.

inflation rate compared to a symmetric strategy and thus reduce the negative inflation bias. Put differently, an asymmetric strategy can potentially compensate for the asymmetry (and the resulting negative inflation bias) induced by the ELB.[3]

We assess the macroeconomic effects of these alternative monetary policy strategies through stochastic simulations of a medium-scale DSGE model (the Two-Agent New Keynesian (TANK) Model developed by Gerke, Giesen and Scheer, 2020a) with parameters estimated based on euro area data.[4] We specify the different history-dependent and asymmetric strategies in the form of simple interest rate rules. In particular, we assess an average inflation targeting (AIT) rule with an averaging window of 4 and 8 years, a price level targeting (PLT) rule, an asymmetric inflation targeting (aIT) and an asymmetric average inflation targeting (aAIT) rule, again with an averaging window of 4 or 8 years. In all cases, the alternative instrument rules augment an inertial Taylor-type rule, which we regard as an inflation targeting (IT) strategy. We calibrate the history dependence and asymmetry as in Work stream on the price stability objective (2021). Importantly, we derive our results under the assumption that all of the monetary policy strategies are credible and well understood by the agents in the economy. The analysis does not, however, incorporate or discuss the potential outcome when those assumptions are not met.[5]

[3] In order to understand how this concept works, it is helpful to first abstract from the ELB. If monetary policy reacts more strongly to negative deviations from the inflation target than to positive deviations, the inflation rate will be better stabilised at its target after disinflationary shocks than after inflationary shocks. If both shocks occur with the same frequency and strength, this would result in an average inflation rate above the target. If the ELB binds occasionally and thereby causes a negative inflation bias, an asymmetric reaction can in principle raise the inflation rate towards its target.

[4] Dobrew, Gerke, Giesen and Röttger (2021) present simulation results for history-dependent and asymmetric strategies based on a heterogeneous agent New Keynesian model.

[5] Additionally, we only compare the stabilisation properties with respect to different instrument rules for the short-term nominal interest rate. In particular, we do not assess other instruments like asset purchases to mitigate the distortions caused by the ELB. On this, see for instance Gerke, Kienzler and Scheer (2021) or Work stream on the price stability objective (2021).

Our simulations reveal a sizeable negative inflation bias for conventional monetary policy (IT) due to the ELB on the short-term nominal interest rate. We illustrate how the likelihood of hitting the ELB, i.e. of interest rates becoming constrained, increases monotonically with a lower equilibrium real interest rate or a lower the inflation target. A combination of low real rates and a low inflation target is especially daunting for monetary policy stabilisation.

There are two main results with respect to alternative monetary policy strategies. First, history-dependent strategies can reduce or even eliminate the negative inflation bias induced by the ELB. They also reduce inflation volatility. We find, as expected, that a higher degree of history dependence reduces the negative inflation bias and the inflation volatility further. Second, asymmetric strategies also reduce the negative inflation bias. A more forceful monetary expansion, when the inflation rate is below the central bank's target (as opposed to above it), raises the average inflation rate. However, in the case of an aIT rule, the reduction in inflation volatility compared to IT is less pronounced than with history-dependent rules.

Additionally, our simulations show that an appropriate calibration of the asymmetry and the overall interest rate rule is warranted. For instance, if the reaction turns out to be too asymmetric, it can ultimately even lead to a positive inflation bias despite the ELB. This is the case in our simulations if the central bank follows an asymmetric and history-dependent rule like aAIT with a 4- or 8-year averaging window. In both cases, we find positive inflation biases, although an aAIT rule reduces the inflation volatility and ELB frequency compared to the IT case.

Finally, and in light of the previous result, we illustrate possible ways to fine-tune an asymmetric strategy to achieve certain objectives, like minimising the inflation bias or inflation volatility. For that purpose, we vary the calibration of the aIT rule in two ways. First, we vary the degree of asymmetry for a given calibration of the other response coefficients in the aIT rule. Second, we optimise for a given degree of asymmetry the reaction of inflation and output growth over a small grid to achieve a certain objective.

Our results are closely related to the model-based assessment of alternative monetary policy strategies within the Eurosystems' strategy review. Specifically, the *work stream on the price stability objective* (WS PSO) analysed, among other things, the properties of history-dependent and asymmetric monetary policy strategies, taking into account the restrictions posed by the ELB. We complement and extend this analysis.[6]

We proceed as follows. Section 2 presents the model, the model parametrisation and the simulation method. Section 3 quantifies the severity of a binding ELB in light of different inflation targets and equilibrium real interest rates. Section 4 illustrates the effects of history-dependent and asymmetric interest rate rules on macroeconomic aggregates. Section 5 explores how an (asymmetric) inflation targeting rule can be adjusted to achieve certain targets. Section 6 concludes.

2 The TANK model

In this section, we present the quantitative evaluation of our model for the set of different instrument rules. Section 2.1 provides a brief summary of the main model ingredients with respect to the TANK model employed for our analysis, the model parametrisation and the numerical model solution. Section 2.2 presents the benchmark instrument rule, i.e. a standard IT rule, as well as a set

[6]See Work stream on the price stability objective (2021) for a detailed presentation and explanation of the analyses carried out by the WS PSO.

of alternative instrument rules that feature history-dependent and/or asymmetric elements for the response of monetary policy to deviations from the central bank's target.

2.1 Framework, parametrisation and solution method

For the analysis we use the Two-Agent New Keynesian (TANK) model developed by Gerke et al. (2020a). The model is based on work by Carlstrom, Fuerst and Paustian (2017), augmented with a second type of household (i.e. hand-to-mouth (H2M) households) and a simple transfer rule, following earlier work by Galí, López-Salido and Vallés (2007) and Bilbiie (2008). Similar to Smets and Wouters (2007), the model features staggered price and nominal wage setting, price and wage indexation, investment adjustment costs and habit formation in consumption. In addition to the households, the model economy includes firms, a central bank and financial intermediaries. The latter finance real investment but their lending capacity is constrained by their net worth.

The H2M households are introduced into the model as follows. A measure $1 - \lambda$ of the households are Ricardian. They have complete access to financial markets and can smooth consumption through short-term deposits and the accumulation of real capital. The remaining fraction λ consists of H2M households who have no access to financial markets (they can neither borrow nor save) and consume their entire (net) labour income and transfers in every period. Firms do not distinguish between the two types of household when hiring labour from a union that is in charge of setting nominal wages, such that the supply of hours and the wage rate are the same across households.

The budget constraint of H2M households is

$$C_t^h = w_t H_t - T_t^h - \tau(Y_t - Y) \quad (1)$$

where their consumption is denoted as C_t^h, labour income as $w_t H_t$, T_t^h are lump-sum taxes and the degree of countercyclical transfers is governed by $\tau \geq 0$, which redistributes income between the two household types whenever aggregate output is different from steady state $(Y_t - Y)$. Details on all the individual sectors of the model economy can be found in Gerke, Giesen and Scheer (2020b).

Table 1: Parametrisation

Parameter	Value
Households	
Habit	0.7897
Inverse Frisch-elasticity	1.7460
Share hand-to-mouth*	0.30
Labor unions	
Wage indexation	0.3443
Calvo wages	0.8581
Wage markup*	0.20
Firms	
Capital share*	0.33
Depreciation rate*	0.025
Price indexation	0.5187
Calvo prices	0.8127
Price markup*	0.20
Inv. adjustment costs	14.2112
Networth adjustment costs	6.5485
Government	
Maturity gov. debt*	10y
Degree of redistribution	0.1756

Notes: Parameters are set to their estimated posterior means (those with an asterisk * are calibrated). A complete table of prior/posterior values is in Gerke et al. (2020b).

The model is estimated based on euro area time series ranging from 1999Q1 to 2014Q4.[7] Table 1 shows the estimated posterior means that are used for the model analysis. The values are in line with estimates for the euro area in similar

[7] For more details on the estimation, see Gerke et al. (2020b).

papers.

To solve and simulate the model with an occasionally binding ELB constraint, we use the extended path algorithm (see Fair and Taylor, 1983) as implemented in Dynare.[8] For the simulations, we employ a version of the model that is linearised around the deterministic steady state.

2.2 Monetary policy rules

This section presents the instrument rules that describe how monetary policy sets the quarterly short-term policy rate R_t in the model. Similar to the simulation protocol of the WS PSO (see Work stream on the price stability objective, 2021), we consider on the one hand the symmetric instrument rules IT, AIT and PLT, which allows us to study how the degree of history dependence affects macroeconomic outcomes.[9] Furthermore, we consider asymmetric versions of IT and AIT, given by aIT and aAIT, respectively, to investigate the additional stimulus provided by an asymmetric policy response to below-target inflation. For AIT and aAIT, we consider two different time horizons over which the average inflation rate is calculated, i.e. 4 and 8 years. This allows us to vary the degree of history dependence between the polar cases of IT and PLT.

$\tilde{R}_t^{(4)}$ describes the annualised nominal shadow interest rate (i.e. the interest rate that would be set in the absence of the effective lower bound). $R^{(4)}$ denotes the annualised long-run nominal interest rate, $\Pi_t^{(4)} = \prod_{k=1}^{4} \Pi_{t-k+1}$ is the annual (year-on-year) price inflation, $\Pi_t^{(4T)} = (1/T) \prod_{k=1}^{4T} \Pi_{t-k+1}$ describes the average annual price inflation over the past T years, Π^4 is the annual inflation target and

[8]See Adjemian, Bastani, Juillard, Karamé, Maih, Mihoubi, Mutschler, Perendia, Pfeifer, Ratto and Villemot (2011).

[9]The rules considered in this paper differ slightly from those used by the WS PSO due to the inclusion of output growth instead of the output gap. While we want to keep the analysis close to that performed in the WS PSO, this adjustment reflects that the model was estimated with the output growth as an argument of the interest rate rule.

Y_t is quarterly real GDP. The price level in the economy is denoted as P_t. Lastly, we define $\hat{X}_t = \log(X_t/X)$, where X is the value of variable X_t in the deterministic steady state.

The monetary policy rules analysed in this paper are as follows:

1. Inflation targeting (IT):

$$\hat{\tilde{R}}_t^{(4)} = 0.85\hat{\tilde{R}}_{t-1}^{(4)} + 0.15\left(\hat{Y}_t - \hat{Y}_{t-1} + 1.5\hat{\Pi}_t^{(4)}\right)$$

2. Average inflation targeting (AIT):

$$\hat{\tilde{R}}_t^{(4)} = 0.85\hat{\tilde{R}}_{t-1}^{(4)} + 0.15\left(\hat{Y}_t - \hat{Y}_{t-1} + \hat{\Pi}_t^{(4)} + T\hat{\Pi}_t^{(4T)}\right)$$

3. Price level targeting (PLT):

$$\hat{\tilde{R}}_t^{(4)} = 0.85\hat{\tilde{R}}_{t-1}^{(4)} + 0.15\left(\hat{Y}_t - \hat{Y}_{t-1} + \hat{\Pi}_t^{(4)} + \hat{P}_t\right)$$

4. Asymmetric inflation targeting (aIT):

$$\hat{\tilde{R}}_t^{(4)} = 0.85\hat{\tilde{R}}_{t-1}^{(4)} + 0.15\left(\hat{Y}_t - \hat{Y}_{t-1} + \hat{\Pi}_t^{(4)}\left(1.5 + \varphi\mathcal{I}_{\left\{\hat{\Pi}_t^{(4)}<0\right\}}\right)\right)$$

5. Asymmetric average inflation targeting (aAIT):

$$\hat{\tilde{R}}_t^{(4)} = 0.85\hat{\tilde{R}}_{t-1}^{(4)} + 0.15\left(\hat{Y}_t - \hat{Y}_{t-1} + \hat{\Pi}_t^{(4)}\left(1 + 0.5\mathcal{I}_{\left\{\hat{\Pi}_t^{(4T)}\geq 0\right\}}\right) + T\hat{\Pi}_t^{(4T)}\varphi\mathcal{I}_{\left\{\hat{\Pi}_t^{(4T)}<0\right\}}\right)$$

For aIT, we set $\varphi = 0.5$ as the baseline value. In Section 5, we will consider different values for the parameter. The annualised short-term nominal interest rate set by the monetary authority is subject to the effective lower bound $R_{ELB}^{(4)}$, such that

$$\hat{R}_t^{(4)} = \max\left\{\hat{\hat{R}}_t^{(4)}, \log(R_{ELB}^{(4)}/R)\right\}.$$

The TANK model is specified in quarterly terms, such that Ricardian households can borrow or save at the nominal interest rate $\hat{R}_t = \hat{R}_t^{(4)}/4$.

The benchmark interest rate rule (IT) is similar to the well-known Taylor rule (see Taylor, 1993). However, the rule we use differs from the traditional rule in two respects. First, our rule features interest rate smoothing, which is specified with respect to the shadow interest rate, rather than the realised interest rate. Second, the inflation rate is defined as year-on-year rather than quarterly inflation. Both elements already induce some history dependence into the benchmark IT rule.[10]

To evaluate the importance of history-dependent strategies, we implement the AIT and PLT rule. The AIT rule differs from the IT and the PLT rule because of the time horizon T used to calculate the average inflation rate. In our analysis, we consider two different time horizons to calculate the average inflation rate: 4 years and 8 years. For $T = 1$, the AIT rule equals an IT rule with a slightly higher inflation response coefficient of 2, rather than 1.5. For sufficiently large T, the AIT rule approximates the PLT rule. The two history-dependent rules, AIT and PLT, imply a commitment to "make up" for past below-target inflation rates by overshooting the inflation target in the future. At the ELB, this can provide additional stimulus due to higher expected inflation and correspondingly lower real interest rates.

Another way to mitigate the negative inflation bias due to the ELB is to respond more aggressively to below-target inflation. The instrument rules aIT and aAIT feature an asymmetric element that captures this idea, with the latter rule

[10]Considering the shadow interest rate as a lagged input argument for the interest rule has an effect akin to forward guidance (see e.g. Coenen, Montes-Galdon and Smets, 2020). Introducing year-on-year inflation as an input argument of the interest rule into a model that is formulated in quarterly terms means that even IT has a small make-up element.

combining the asymmetric element with history dependence.

Before turning to the quantitative performance of the different rules, the next section takes a look at the extent to which monetary policy is constrained by the ELB under a standard, i.e. symmetric, inflation targeting strategy, and how this depends on certain parameters.

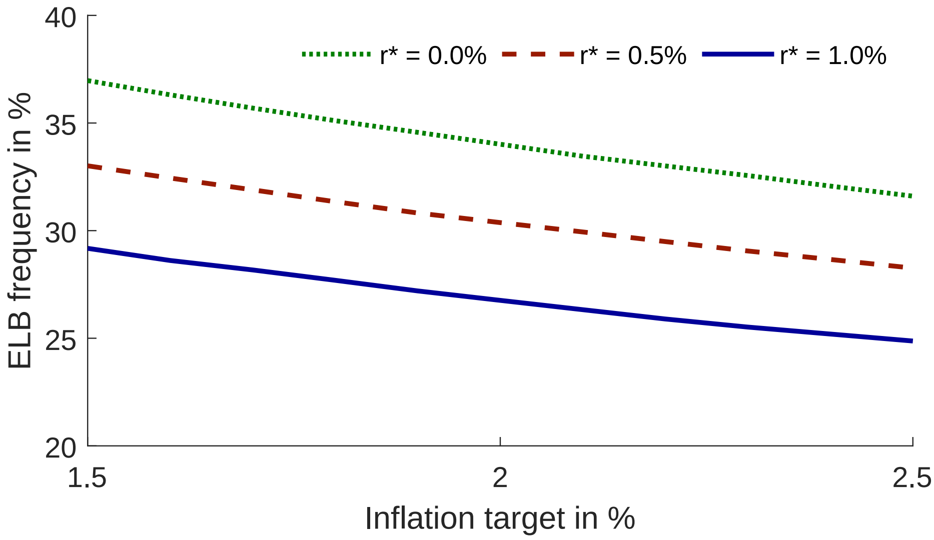
3 The probability of hitting the ELB

This section quantifies the ELB frequency for different levels of the (annual) inflation target, denoted as $\Pi^* \equiv \Pi^4$, and the (annual) long-run equilibrium real interest rate, denoted by r^*. The ELB is set to −0.5%. We run 2,500 simulations, each with 200 periods where we discard the first 100 periods to eliminate the impact of initial conditions. The shocks (technology shock, financial shock, investment shock, wage markup shock, price markup shock, discount factor shock) are drawn from the estimated distributions. Figure 1 shows the ELB frequency for different combinations of Π^* (ranging from 1.5% to 2.5%) and r^* (0%, 0.5%, 1%).

We obtain the following results:

A lower r^* increases the likelihood of hitting the ELB. Take, for example, the 2% inflation target. A reduction of r^* from 1% (blue solid line) to 0.5% (red dashed line) increases the probability of hitting the ELB by approximately four percentage points (pp) from 27% to 31%. A further reduction of r^* to 0% (green dotted line) increases the ELB frequency by another 4pp.

Figure 1: ELB frequency conditional on the target inflation rate and r^*



A lower Π^* increases the frequency of hitting the ELB. For example, assuming $r^* = 0.5\%$ (red dashed line), a decline of Π^* from 2% to 1.5% increases the ELB frequency by approximately 3pp from 30% to 33%.

Combinations of low real rates and low inflation target rates are particularly daunting scenarios for monetary policy. A combination of an r^* of 0% (green dotted line) and a target inflation rate of 1.5% yields an ELB frequency of about 37%.

4 Comparison of alternative interest rate rules

Given that conventional monetary policy might be frequently constrained by the ELB in a low interest rate environment, this section evaluates the extent to which alternative monetary policy strategies can help reduce the incidence and economic costs of the ELB. To this end, we use the model to study the stabilisation properties of alternative interest rate rules, with the IT rule serving as our benchmark. We first discuss the stabilisation properties of symmetric interest

Table 2: Simulation results for various interest rate rules

	ELB		Inflation (%)		Output gap (%)	
Interest rate rule	Freq.(%)	Dur.(qrt.)	Mean	Std	Mean	Std
IT	30.37	18.42	1.28	5.12	-4.92	6.13
AIT(4)	30.54	17.22	1.44	2.55	-2.44	7.33
AIT(8)	21.11	12.46	1.87	1.90	-0.58	7.10
PLT	16.32	9.93	2.00	1.80	-0.17	7.21
aIT	30.02	17.87	1.70	4.89	-3.36	6.49
aAIT(4)	21.04	14.19	3.09	3.40	1.96	7.09
aAIT(8)	13.00	8.60	3.37	2.65	2.95	7.46

rate rules. Then, we turn to the ones that (additionally) feature asymmetric elements.

4.1 Symmetric monetary policy rules

Taken on its own, history dependence can notably reduce the frequency of ELB episodes. As shown in Table 2, this improvement is particularly visible for PLT, which is the most history-dependent rule we consider. PLT generates a markedly lower standard deviation of inflation and fewer ELB episodes with a shorter average duration than IT and AIT (both with a $T = 4$ and $T = 8$ averaging window), which lies between PLT and IT with respect to its history dependence.

Price level targeting induces a strong stabilising effect via agents' expectation. In the case of a disinflationary (inflationary) shock, agents expect inflation to overshoot (undershoot) in the future so that the price level eventually returns to its target path. The expectation of higher (lower) inflation rates in the future already stabilises inflation today, which leads to a less volatile inflation rate. This automatic stabiliser implies that the central bank does not have to use its interest rate instrument as vigorously as in the case of IT and AIT. This results in a lower ELB frequency and a lower average duration of ELB episodes for PLT relative to the other two symmetric strategies

The benefits of history-dependent monetary policy show up in lower negative biases in inflation and output. Specifically, PLT delivers an average inflation rate that is in line with the target-path inflation rate of 2%, whereas IT implies a sizeable downward inflation bias, with an average inflation rate of only 1.28%. For AIT, the average annual inflation rate is about 1.44% for the 4-year averaging window and 1.87% for the 8-year averaging window. While the output gap exhibits a downward bias vis-à-vis the steady-state value of zero due to the ELB for all rules under consideration, PLT exhibits the smallest and IT the largest downward bias with respect to the output gap. AIT(4) and AIT(8) again fall between the two polar history dependence cases.

History-dependent rules lead to lower inflation volatility. We find that the standard deviation of inflation is around 65% lower for PLT than for IT, and that the ELB frequency is 14pp lower (30% versus 16%). Comparing the two AIT variants and IT, we find that the former two generate lower inflation volatility than the latter. Much like PLT, albeit less strongly, AIT also incorporates an automatic stabiliser mechanism that raises (lowers) inflation expectations whenever the inflation rate is below (above) the target value. Accordingly, a longer averaging window stabilises inflation more effectively. For instance, consider the reduction in the volatility of inflation for the AIT(8) rule relative to the less history-dependent AIT(4).

The better inflation stabilisation properties of history-dependent rules come at the cost of higher output volatility. This observation is due to sticky wages in the model. In the case of supply shocks, which play a prominent role in the model's estimation, make-up strategies stabilise inflation strongly, such that the burden of (inefficient) real wage adjustments falls on nominal wage adjustments. With sticky nominal wages, this translates into large output fluctuations. The standard deviation of the output gap is 1pp lower for IT than for PLT and for AIT.

4.2 Asymmetric monetary policy rules

Asymmetric inflation targeting reduces the downward inflation bias vis-à-vis standard inflation targeting. However, the frequency and average duration of ELB episodes are only slightly lower compared to IT. While the more accommodative policy during times of below-target inflation lowers the downward biases in inflation (with average inflation going from 1.28% to 1.70%) and output (with an output gap of −3.36% instead of −4.92%), inflation volatility declines only mildly.

Asymmetric average inflation targeting reduces ELB incidence but causes upward inflation bias. These two findings are, of course, related since a higher average inflation rate raises the average nominal rate and therefore the distance to the ELB. Whenever the average annual inflation rate, calculated over the past T years, is below the target inflation rate, AIT switches from an IT rule to an AIT rule. In contrast to aIT, monetary policy thus not only becomes more aggressive during periods of below-target inflation but remains accommodative until past inflation target deviations are made up for. The combination of these two features, history dependence and an asymmetric response, causes the ELB frequency to decline substantially but also leads the inflation rate to overshoot the target on average by more than 50%, with values of 3.09% for the aAIT(4) rule and 3.37% for the aAIT(8) rule, respectively. The aAIT rules also results in an upward bias in output relative to steady state, which increases again with the degree of history dependence. Lastly, inflation volatility under aAIT is lower and output volatility is higher than for IT.

In terms of overall performance, the asymmetric rules under consideration are located between IT and PLT. Compared to the symmetric history-dependent rules (PLT and AIT), we observe that asymmetric rules stabilise inflation less powerfully. For aAIT, inflation is now above target on average and more volatile. For aIT, the downward inflation bias is lower relative to AIT(4) but not relative to AIT(8) and PLT. In addition, inflation becomes much more volatile under aIT compared to the symmetric history-dependent rules. Relative to the baseline IT rule, the results are somewhat mixed. In the next section, we take a closer look at how an asymmetric response function alone can be fine-tuned to achieve a better performance along the dimensions of interest.

5 The case of asymmetric inflation targeting

So far, we have only compared the performance of various rules for a given constellation of parameters. However, the design of monetary policy rules offers a high degree of freedom when it comes to the calibration of the different interest rate rules. Until now, the rule has been calibrated based on the simulation protocol of the WS PSO. In principle, the performance of all the rules under consideration could likely be improved by adjusting the rule parameters in an appropriate way. Specifically, it could generally be the case that IT comes with better stabilisation properties if the rule parameters are chosen to achieve certain targets, like hitting the inflation target or reducing macroeconomic volatility. However, compared to IT, we have shown that under rational expectations symmetric make-up strategies, such as PLT or AIT(T) with a sufficiently large averaging window T, can already largely undo the negative inflation bias and the higher volatility induced by the ELB.[11] It is therefore to be expected that after optimising the rule parameters for AIT and PLT as well as for IT with respect to certain targets, the same results will prevail.

We therefore now focus on asymmetric inflation targeting and the extent to which an asymmetric element alone can lead to improved stabilisation properties once the rule's parameters are adjusted. To that end, we now consider the rule

$$\hat{\tilde{R}}_t^{(4)} = 0.85\hat{\tilde{R}}_{t-1}^{(4)} + 0.15\left(\phi_Y\left(\hat{Y}_t - \hat{Y}_{t-1}\right) + \hat{\Pi}_t^{(4)}\left(\phi_\Pi + \varphi\mathcal{I}_{\left\{\hat{\Pi}_t^{(4)}<0\right\}}\right)\right).$$

We thus now allow the coefficient for inflation (ϕ_Π) and the coefficient for output growth (ϕ_Y) to differ relative to Section 4. Together with the asymmetric response coefficient φ, this leaves us with three parameters that can be adjusted.

We vary the calibration of the asymmetric IT rule in two ways. First, we only change the value φ while leaving the other parameters unchanged. This comparative statics experiment allows us to illustrate how a more forceful response to below-target inflation affects outcomes.[12] Second, we optimise the monetary policy rule for different degrees of asymmetry φ. In particular, for a given φ, we choose the inflation coefficient ϕ_Π and the output growth coefficient ϕ_Y to minimise a certain target.

[11] These findings are in line with the literature, see e.g. Bernanke et al. (2019), Arias et al. (2020), Coenen et al. (2021).

[12] This implies that $\phi_\Pi = 1.5$ and $\phi_Y = 1$. Note that the specification $\varphi = 0$ yields a standard inflation targeting rule without an asymmetric element. The case with $\varphi = 0.5$ is the one analysed in Section 4.

Table 3: Simulation results for different aIT rule parameters

aIT rule	ELB		Inflation (%)		Output gap (%)	
φ	Freq.(%)	Dur. (qrt.)	Mean	Std	Mean	Std
0.00	30.37	18.42	1.28	5.12	-4.92	6.13
0.25	30.26	18.41	1.51	4.99	-4.08	6.32
0.50	30.02	17.87	1.70	4.89	-3.36	6.49
0.75	29.71	17.31	1.87	4.80	-2.73	6.64
1.00	29.60	16.93	2.02	4.73	-2.18	6.77
1.25	29.32	16.56	2.15	4.66	-1.70	6.87
1.50	29.17	16.38	2.27	4.60	-1.27	6.96
1.75	29.12	16.15	2.37	4.54	-0.89	7.04
2.00	29.02	16.07	2.47	4.49	-0.55	7.10
3.00	29.02	15.47	2.75	4.31	0.54	7.26
4.00	29.20	15.24	2.96	4.16	1.32	7.34
5.00	29.54	15.07	3.11	4.04	1.91	7.37
8.00	30.51	14.71	3.40	3.78	3.12	7.42
10.00	31.01	14.99	3.54	3.64	3.67	7.43
15.00	31.82	15.00	3.77	3.42	4.63	7.48

5.1 A more forceful response to below-target inflation

A higher degree of asymmetry reduces the downward inflation bias and lowers the standard deviation of inflation in a monotonic way. A higher value for φ implies a more forceful response to below-target inflation which, as shown in Table 3, better allows the inflation rate to be stabilised, while closing the gap between the inflation rate and the target value for sufficiently high φ.[13] For $\varphi > 1$, which is only slightly higher compared to the baseline calibration considered in the previous section, the inflation rate overshoots its target of 2%.

A more aggressive inflation targeting also monotonically raises the output gap on average, while increasing its volatility. As in the case of the inflation rate, this relationship is again a monotonic one. The mean of the output gap also increases monotonically with φ as well as its standard deviation. While $\varphi < 3$ implies a negative output gap, $\varphi \geq 3$ implies a positive value.

[13] For φ, we consider values from 0 to 15. For even higher values, we encountered problems with respect to the numerical solution method.

For the relationship between the asymmetric response coefficient φ and the time spent at the ELB, we observe an inverse hump-shaped pattern. For $\varphi > 0$ to $\varphi = 2$, an increase in the asymmetric response coefficient lowers the ELB frequency but raises it for $\varphi > 2$. The magnitude of these changes is, however, rather small, with values ranging between 29.02% and 31.82%.

5.2 Different calibrations of the monetary policy rule

Different calibrations of the monetary policy rule can enhance the stabilisation properties of asymmetric rules. In this subsection, we vary the "conventional" response coefficients on inflation (ϕ_Π) and output growth (ϕ_Y) for different degrees of asymmetry (φ). Specifically, we consider parameter combinations based on the sets $\varphi \in \{0, 0.25, 0.5, 1, 1.5\}$, $\phi_\Pi \in \{1.1, 1.5, 2, 2.5, 3.5, 5\}$ and $\phi_Y \in \{0.1, 0.25, 0.5, 0.75, 1, 1.5\}$. After we have simulated the model for all possible parameter combinations, we look at those combinations that minimise certain targets. Specifically, we consider the standard deviation of inflation, the average inflation rate and the ELB frequency as potential targets. The results for the "optimised rule" are displayed in Table 4.

The ELB frequency is minimised by a passive standard inflation targeting rule, i.e. when there is no asymmetric element. This case corresponds to the parameter combination $(\varphi, \phi_\Pi, \phi_Y) = (0, 1.1, 0.1)$. The monetary policy implied by this specification is quite passive in the sense that it does not respond much to deviations of inflation from the 2% target and output growth from its long-run value of 0. Table 4 also reveals that minimising the ELB frequency does not necessarily result in a good performance with respect to achieving the inflation target and inflation stabilisation.[14]

[14]Indeed, the inflation rate associated with the parameter combination that minimises the ELB frequency is 1.88%, whereas it is 2.02% for the combination that minimises the deviation

Table 4: Optimised asymmetric inflation targeting rule

	Objective	Optimum	ϕ_Π	ϕ_Y
$\varphi = 0$	ELB frequency	27.23	1.1	0.1
	Abs. dev. from inflation target	0.12	1.1	0.1
	Std. of inflation rate	3.51	5	0.1
$\varphi = 0.25$	ELB frequency	29.07	1.1	0.25
	Abs. dev. from inflation target	0.09	1.1	1.5
	Std. of inflation rate	3.47	5	0.1
$\varphi = 0.5$	ELB frequency	29.48	1.1	1.5
	Abs. dev. from inflation target	0.13	1.5	0.1
	Std. of inflation rate	3.43	5	0.1
$\varphi = 1$	ELB frequency	28.96	1.1	1.5
	Abs. dev. from inflation target	0.02	1.5	1
	Std. of inflation rate	3.35	5	0.1
$\varphi = 1.5$	ELB frequency	28.43	1.1	1.5
	Abs. dev. from inflation target	0.19	2	0.1
	Std of inflation rate	3.28	5	0.1

The inflation rate is closest to its target for medium values of the asymmetry and monetary policy reaction to inflation and output. The associated objective that is minimised in this case is given by the absolute value of the gap between the average inflation rate and the long-run inflation target. The optimum is achieved in this case for the parameter combination $(\varphi, \phi_\Pi, \phi_Y) = (1, 1.5, 1)$.

Minimising the volatility of inflation is achieved by a strong asymmetry, a very aggressive response to inflation and a minimal response to output. Within the parameter space under consideration, this implies inflation coefficients set as high as possible, $(\varphi, \phi_\Pi) = (1.5, 5)$, whereas the response of monetary policy to output growth is muted as far as possible ($\phi_y = 0.1$).

To sum up, an asymmetric orientation of monetary policy is likely to be suitable for reducing the negative inflation bias. However, the calibration and thus the well-dosed use of the instruments remains crucial.

from the inflation target.

The results in this section show that, for a given objective, an appropriately chosen calibration allows an improvement in the performance of aIT relative to the case outlined in Section 4. However, the findings from Section 5.2 also illustrate that a stabilisation of inflation does not necessarily go hand in hand with a minimisation of the deviation from the inflation target. Ultimately, monetary policymakers may hence face a trade-off between the level and the volatility of inflation when it comes to the design of an asymmetric monetary policy strategy. It is therefore important to explore this trade-off in more detail in subsequent work.

6 Conclusion

Based on simulation studies carried out with a TANK model, we find that symmetric history-dependent strategies, like average inflation targeting (AIT) or price level targeting (PLT), can lower ELB incidences and – as a result – reduce negative biases in inflation and output. Moreover, history dependence helps stabilise inflation but comes with a higher degree of output volatility compared to a standard inflation targeting (IT) rule. The performance of asymmetric strategies, like aIT or aAIT, falls between that of IT and AIT/PLT.

We assess the potential of asymmetric strategies further by investigating how the performance of aIT is affected by different calibrations of the associated interest rate rule. Specifically, we find that by varying the parameters of such a rule, it is possible to achieve a better performance with respect to specific targets, like reducing the downward inflation bias or stabilising inflation. However, achieving different targets at the same time may prove to be challenging under aIT. Hence, a more systematic analysis of the calibration of asymmetric strategies is warranted.

In addition to the uncertainty surrounding the calibration of asymmetric monetary policies, it is important to note that there are important caveats when attempting to derive specific policy implications from our analysis. In particular, the agents in the model form rational expectations. To the extent that firms or households do not perfectly understand or even misperceive the communication of monetary policymakers, our results are likely an upper bound for the potential aggregate effects. This applies especially to history-dependent strategies.

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