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Monetary policy strategies to navigate post-pandemic inflation: an assessment using the ECB’s New Area-Wide Model

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Abstract

We assess the effectiveness of ECB monetary policy in the post-pandemic period using a state-of-the-art estimated DSGE model of the euro area. Through counterfactual experiments varying the timing of interest rate hikes, policymaker preferences, and optimality criteria, we compare alternative strategies against actual policy. The ECB's decision to begin hiking the policy rate in 2022:Q3 effectively balanced inflation and output stabilization, leading to a brief slowdown and inflation converging to target by end-2025. An earlier hike in 2021:Q4 would have reduced peak inflation but caused a prolonged recession, while a delayed hike to 2024:Q1 would have fueled persistent inflation above 4% until 2026. Optimal policy simulations indicate that a more aggressive tightening could have lowered inflation volatility only at the cost of deeper contractions in GDP. Real-time monetary policy counterfactuals confirm that actual policy closely aligned with optimal prescriptions, effectively managing the trade-off between inflation and growth.

Keywords: estimated DSGE model, monetary policy frameworks, optimal policy, dual mandate, euro area

JEL classification: C53, E31, E42, E52, E58

Non-technical summary

We assess the impact of ECB monetary policy on macroeconomic outcomes by focusing on changes to interest rate policy in the post-pandemic environment. To do so, we employ the New Area-Wide Model (NAWM II) (Coenen et al. (2018)), the workhorse DSGE model for policy analysis at the ECB, and confront it with alternative, counterfactual monetary policy strategies since mid-2021. We contrast the impact of actual policy against alternative strategies that differ in their timing, optimality, and reflection of monetary policymaker preferences.

Assuming full information about the macroeconomic conditions that would prevail since 2021, the estimated Taylor-type rule of the NAWM II suggests that an earlier hike would have reduced somewhat the peak of inflation and achieved convergence to the target faster. Instead, activating the rule in 2022:Q3, i.e., the timing of the start of the actual hiking cycle, delivers broadly similar outcomes to actual policy conduct, suggesting that the NAWM II tracks relatively well observed policy. Instead, ”looking-through” the full sequence of supply shocks and leaving policy rates unchanged until the beginning of 2024 would have led to significantly higher inflation.

Second, we contrast the behaviour of the estimated model rule to optimal policy counterfactuals whereby the central bank endogenously chooses the path of the short term rate to minimize an empirically supported welfare loss function. Under optimal policy, interest rate paths are more hump-shaped, with higher peak rates but less persistence of the restrictive stance. Returning to price stability while achieving a ”soft-landing” depends on the choice of the preference parameters and lift-off date. Overall, the proximity of some benchmark optimal policy counterfactuals with the baseline, indicates that actual policy conduct succeeded in implementing an efficient management of the output-inflation trade-off.

Third, we simulate policy counterfactuals in real-time by updating projections each quarter between 2021:Q4 and 2023:Q4 with new vintages of incoming data and macroeconomic baselines. Our results suggest that, unlike the cases of perfect foresight, there does not exist a strong rationale for hiking policy rates aggressively early. Instead, real-time prescriptions call for a less steep interest rate increase, which is however more persistent than in the full-information counterfactuals. The real-time simulations confirm that actual policy fares well against alternative policy conducts and that there was little room to improve welfare.

We next compare stabilisation and welfare metrics implied by each strategy over time. We find that most alternative strategies, with the exception of an extended lower-for-longer policy where the hiking cycle is initiated in 2024:Q1, improve price stability relative to actual policy. That said, no strategy improves both GDP and inflation volatility relative to actual policy, implying that price stability can be only achieved at the cost of increased output volatility. In terms of a normative comparison, optimal policy strategies are generally associated with lower welfare losses relative to actual policy—in particular under more hawkish preferences of the central bank and when initiating the hike earlier—suggesting that the actual policy conduct managed to implement an efficient management of the output-inflation trade-off.

Finally, as the validity of our findings rely on the validity of the model itself, we discipline the uncertainty around key dimensions by undertaking robustness checks on: the specification of policymaker preferences in the central bank's loss function, the strength of the transmission of policy through the economy, and by assuming alternative ways in which agents form expectations.

1 Introduction

In response to increasing inflation in 2021, the European Central Bank (ECB) took key actions to unwind its accommodative monetary policy stance. In terms of its primary instruments: 2022:Q3 marked the end of an extended period where the deposit facility rate stood near the effective lower bound since the outbreak of the sovereign debt crisis in 2012. The short-term interest rate was raised from -0.5% in 2022:Q3 and reached 4.0% four quarters later in 2023:Q3. Notwithstanding the tightening in monetary policy, inflation in the euro area peaked at 10% in 2022:Q4 and has been declining since then, to 2.7% in 2023:Q4. According to the projections published by the ECB in December 2023 this figure is expected to converge to the 2% medium-term target in 2025.

How successful was ECB monetary policy at stabilizing euro area inflation and GDP in the post-pandemic period? We employ the workhorse dynamic stochastic general equilibrium (DSGE) model used for policy analysis at the ECB—the New Area-Wide Model II (NAWM II) (Coenen et al. (2018))—to assess the effectiveness of the ECB's monetary policy in stabilizing inflation and real activity during this volatile post-pandemic period. In particular, we conduct alternative monetary policy experiments, which differ in their timing of interest rate tightening, the specification of policymaker preferences, and their optimality with respect to stabilization and welfare-based metrics. Our intention is to contrast the effectiveness of these alternative monetary policy strategies against the impact of actual policy against using a state-of-the-art DSGE policy model tailored to provide quantitative prescriptions regarding euro area monetary policy.

Our results suggest that the ECB was relatively effective in stabilizing inflation and output, though not without trade-offs. The model-based analysis suggests that the actual policy path—whereby the hiking started in 2022:Q3—resulted in a brief economic slowdown, with inflation converging to target by end-2025, and a peak rate of 4%. An earlier rate lift off in 2021:Q4 would have reduced peak inflation (8% vs. 10%) but at the cost of a prolonged recession. A delayed lift off to 2024:Q1 would have boosted growth but led to more persistent inflation (above 4% until 2026). Optimal policy simulations indicate that a more hawkish stance could have reduced inflation volatility but at the expense of a deeper recession. Real-time counterfactuals confirm that actual policy closely followed optimal prescriptions, striking an efficient balance between inflation and output stabilization. Most alternative strategies, except for a delayed tightening, improved price stability but increased output volatility, reinforcing the notion that the ECB effectively managed the trade-off between inflation and growth.

Our setup builds on recent studies that assess counterfactual monetary policy strategies during the post-pandemic inflation period, extending the analysis from the US to the euro area. For instance, Crump et al. (2023) use the New York Fed's DSGE policy model to simulate counterfactual monetary policy strategies of the Federal Reserve, while De Fiore et al. (2023) compare actual US monetary policy to alternative monetary policy frameworks using an estimated policy model. Our work extends these studies by offering a model-based evaluation of key ECB monetary policy decisions of the recent years using the ECB's estimated policy model. In particular and differently to others in the literature, it allows for policy to be counterfactually set in an optimal manner and to evaluate its effectiveness by changing the information set of the central bank, that is by taking a perfect-foresight perspective where all future realized shocks are known with certainty, or a real-time approach where only past shocks are observed by the central bank and future shocks are derived from vintages of official staff projections. In this regard, our work is related to several other studies analyzing the effects of monetary policy rules in real time, such as e.g., Orphanides (2001), Molodtsova et al. (2008), and Altavilla and Ciccarelli (2011), among others, although, to the best of our knowledge, this is the first paper to assess the real-time effects of *optimal* monetary policy effectiveness using a large-scale structural model.

In a first step, we ask the counterfactual question of whether the timing of the hike mattered. In particular, with hindsight of the evolving macroeconomic conditions and conditional on the most recent macroeconomic projections, how effective was euro area monetary policy in stabilizing inflation by choosing 2022:Q3 to raise interest rates? And what would have happened to interest rates, output, and inflation had the ECB chosen to begin its tightening cycle at different points in time since 2021:Q4 when inflationary pressures started to materialize?

According to the NAWM II, aligning the timing of the lift off with actual policy decisions—starting in 2022:Q3—suggests that interest rate hikes would have initially been somewhat steeper, but tightening would have proceeded more gradually thereafter, with rates peaking at 3.75% in 2024:Q2 rather than 4% as observed in practice. In this event, the economic slowdown would have been brief but inflation in 2024 would have been higher by 0.3 percentage points and converged to the 2% target by the end of 2025. Instead, an earlier interest rate hike beginning in 2021:Q4 would have limited the inflation peak to 8% rather than 10% albeit at the cost of a protracted recession in 2022 and 2023. By contrast, a counterfactual where monetary tightening is delayed to 2024:Q1—representing a strong commitment to "look through" the sequence of inflationary supply shocks—would have resulted in significantly higher economic growth but a more entrenched inflationary environment, where inflation would have peaked around 10.5% and remained above 4% until 2026.

While the first set of counterfactual strategies assumes monetary policy follows the estimated interest rate rule of NAWM II, a natural question arises: what would the effects have been if, for each hike's starting date, monetary policy had been designed optimally? To answer this question we compute a set of optimal interest rate paths at different points in time, determined by means of minimizing an intertemporal loss function conditional on the latest baseline projections available for the euro area. Our application is similar in spirit to other studies employing large-scale DSGE models to assess optimal monetary policies under commitment using predetermined loss function specifications, for example, see, Adjemian et al. (2007); Adolfson et al. (2011); Darracq Pariès and Kühl (2016); de Groot et al. (2021); Mazelis et al. (2023) and Harrison and Waldron (2021). In particular, our analysis is complementary to parallel work by Carrier and Mavromatis (2024), who analyze optimal normalization strategies during the post-pandemic period in a setting where inflation expectations may become de-anchored. While their behavioral model explicitly captures nonlinearities arising from expectation dynamics, our model prioritizes empirical fit by allowing for policy-relevant transmission channels and estimating its parameters based on observed data.

To solve for the optimal policy in the NAWM II we employ the constrained optimal policy projection from de Groot et al. (2021). Harrison and Waldron (2021), Barnichon and Mesters (2023), McKay and Wolf (2023), Carrier and Mavromatis (2024) and Dengler et al. (2024) have employed similar frameworks in related studies. Compared to the rule-based counterfactuals, the optimal policy counterfactuals are more hump-shaped, with higher peak rates but less persistence of the restrictive stance. Here, picking 2022:Q3 as the initial date of monetary tightening would engineer a mild recession and deliver inflation outcomes similar to those observed in the data and under the rule-based counterfactual. The more hawkish preferences would imply a deeper recession and inflation undershooting the target by 2024 already.

Although the retrospective analysis yields important conclusions about the effectiveness of euro area monetary policy, in practice, policy decisions are made in real time, based on the information set available at each point in time, rather than with the benefit of hindsight. As a result, policy mistakes can arise not only from misjudging the economic outlook but also from failing to react promptly to new developments. Our third set of exercises therefore relaxes the assumption of perfect information from the perspective of the central bank, and assesses the effectiveness of an optimal *real-time* monetary policy. By analyzing real-time policy counterfactuals, we assess how policymakers responded to shocks as they unfolded, distinguishing between the impact of unforeseen events and the role of policy choices in shaping macroeconomic outcomes. This approach—which to our knowledge is novel to the literature from the perspective of large-scale structural models—provides a more realistic evaluation of monetary policy effectiveness than assuming perfect foresight of the baseline projection and shocks.

In this setting, we update optimal monetary policy counterfactuals each quarter between 2021:Q4 and 2023:Q4, reflecting new vintages of incoming data and macroeconomic projections. Our results suggest that, unlike in simulations with perfect foresight about the sequence of shocks hitting the economy, in real time there is no strong rationale for hiking policy rates aggressively already in 2022:Q1. Instead, real-time prescriptions call for a less steep interest rate increase, which is however more persistent than in full-information counterfactual simulations. The real-time simulations confirm that actual policy fares relatively well against alternative policy conducts. In particular, the actual rate path aligns more closely with real-time optimal policy projections than with the model's estimated interest rate rule.

Given the numerous monetary policy strategies evaluated so far, we compare stabilisation and welfare metrics implied by each strategy over time. We find that most alternative strategies, with the notable exception of an extended lower-for-longer policy where the hiking cycle is initiated in 2024:Q1, improve price stability relative to actual policy. That said, no strategy improves both GDP and inflation volatility relative to actual policy, implying that inflation stabilization can only be improved at the cost of increased output volatility. In terms of a normative comparison, optimal policy strategies are generally associated with lower welfare losses relative to actual policy, in particular under more hawkish preferences of the central bank and when initiating the hike earlier. Overall, the proximity of the benchmark optimal policy macroeconomic allocation with the observed macroeconomic baseline, indicates that the actual policy conduct managed to implement an efficient management of the output-inflation trade-off.

It is important to recognize that the validity of these simulation results, and their corresponding welfare assessment, depends on the model's underlying assumptions. Specifically, the analysis relies on a first-order approximation to describe the model's dynamics. Given the large shocks observed during the periods examined, some nonlinear effects may not be fully captured, potentially leading to less persistent impacts or muted responses, thereby understating the welfare losses associated with different strategies. Furthermore, the model assumes that longer-term inflation expectations remained anchored throughout the analysis period. While this assumption appears reasonable in hindsight, it may influence the results by dampening potential feedback effects on inflation dynamics and, consequently, welfare, particularly in times of heightened uncertainty.

We take steps to mitigate uncertainty around key model assumptions by conducting robustness checks on the strength of policy transmission——specifically, through variations in the slope of price and wage Phillips curves and the degree of financial frictions. These sensitivity analyses help address concerns about nonlinearity by exploring different regimes in which policy transmission operates differently. We find that under a steeper Phillips curve a lower increase in the policy rate would be sufficient to limit the peak of inflation relative to the benchmark case, while output would have decreased by less. Moreover, under a stronger degree of financial frictions (captured by an increase in households' portfolio adjustment costs) the central bank faces a larger sacrifice ratio, leading similar interest rate hikes to produce disinflation but at a higher output cost. Finally, we also highlight the importance of agent expectations in shaping the predictions of optimal policy. We find that expectations influence the optimal interest rate trajectory with policy announcements further away in the future being less effective when deviating from rational expectations.

The remainder of this paper is structured as follows. Section 2 introduces the ECB's estimated DSGE model and provides an overview of its key features. Section 3 illustrates the several counterfactual monetary policy strategies, while Section 4 performs robustness checks around key transmission mechanisms. An Appendix provides additional figures and information on extensions.

2 An Overview of the Model

We use as a laboratory the NAWM II, the workhorse estimated DSGE policy model of the ECB, which has been designed for use in the Eurosystem's (Broad) Macroeconomic Projection Exercises (BMPE) and for analysis of topical policy issues affecting business cycle fluctuations.[0] The model comprises the euro area and a rest-of-the-world block. It is estimated using Bayesian techniques and the list of observables includes key financial variables, in particular bond yields and bank lending rates. In light of the large number of time series used for estimation, the model features 24 distinct structural shocks. In what follows we provide an overview of the model's main features, with a focus on outlining key relationships within the financial sector.[1]

NAWM II is an open-economy DSGE model with financial intermediaries and features seven types of economic agents: households, firms, wholesale banks, retail banks, capital producers, a fiscal authority and the central bank.

Households Households make optimal choices regarding their purchases of consumption and investment goods, the latter determining the economy-wide capital stock. They supply differenti-

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[0] See e.g., Cecion et al. (2021), and Brand et al. (2021) (and references therein) for recent applications of the NAWM II model related to price stability, the inflation-output trade off, among other key topical issues. See also Ciccarelli et al. (2024) for an overview of ECB policy uses and applications using the NAWM II.

[1] For a detailed description of the model's structure see, Coenen et al. (2018), while for a detailed exposition of the ECB macroeconomic projection exercise see, ECB (2016)

ated labour services in monopolistically competitive markets, and set wages as a mark-up over the marginal rate of substitution between consumption and leisure.

In terms of financial assets, households can place deposits in the amount of $D_{h,t+1}$ to wholesale banks and receive a (gross) return $R_{D,t-1}$ on previous-period deposits. They can also hold short-term (one-period) government bonds, B_{t+1}, and invest in domestic long-term government bonds subject to portfolio adjustment frictions:

$$\Gamma_L^h(B_{L,h,t+1}) \quad = \quad 1/2\,\gamma_L^h\left(B_{L,h,t+1}-\overline{B}_{L,h}\right)^2/\,\overline{B}_{L,h} \tag{1}$$

For purchasing investment goods,$I_{h,t}$, households demand loans, which are originated by wholesale banks and distributed by retail banks. At the retail level, loans are nominal consoles with geometrically decaying coupons (as in Woodford (2001)) with $\mathcal{Q}_{I,t}\,B_{I,t+1}$ denoting the loan value and $\mathcal{R}_{I,t}=\frac{1}{\mathcal{Q}_{I,t}}+\varrho_I$ denoting the loan rate ("yield to maturity") where $\mathcal{Q}_{I,t}$ is the discount price of the loan $B_{I,t+1}$ and ϱ_I refers to the decay factor of the coupons. Demand for loans arises as households face a "loan-in-advance" (LIA) financing constraint for investments in physical capital (as in Carlstrom et al. (2017)):

$$P_{C,t}\;\tilde{p}_{I,t}\,I_{h,t} \quad \leq \quad \mathcal{Q}_{I,t}\left(B_{I,t+1}-\varrho_I B_{I,t}\right), \tag{2}$$

where $\tilde{p}_t^I$ is the relative price of the investment good obtained from the capital good producer. In turn, the value of the loan for household h can be expressed as $\tilde{p}_{I,t}\,(1+\varsigma_{h,t}) = Q_{h,t}\,\epsilon_t^I$ where $\varsigma_{h,t}\,\Lambda_{h,t}/P_{C,t}$ is the Lagrange multiplier associated with the household's LIA constraint and $Q_{h,t}$ represents Tobin's Q.

Wholesale and retail banks The investment loans are supplied by wholesale and retail banks, which act as financial intermediaries. First, wholesale banks use the deposits raised from the households and their net worth to issue wholesale loans and to purchase domestic and foreign long-term bonds. Second, retail banks purchase the wholesale loans, transform them into retail loans and offer these retail loans to the households. Because of the financing constraint on the part of the households, the production of new physical capital is separated from the households' decision problem and relegated to capital producers.

In particular, banks' assets comprise long-term loans to the private sector for investment purposes, $B^p_{I,b,t+1}$ domestic, $B^p_{L,b,t+1}$, and foreign, $B^{*,p}_{L,b,t+1}$, government bonds and reserves held at the central bank. On the liabilities side, they finance themselves via the collection of short-term deposits and retained earnings. Their balance sheet is hence given by:

$$\tilde{\mathcal{Q}}_{I,t}B^p_{I,b,t+1}+\mathcal{Q}_{L,t}B^p_{L,b,t+1}+S_t\mathcal{Q}^*_{L,t}B^{*,p}_{L,b,t+1} \quad = \quad NW_{b,t}+D^h_{b,t+1} \tag{3}$$

Reflecting an agency problem where banks must hold sufficient capital to reassure their creditors that they will not divert funds, banks are subject to a (risk-weighted) leverage constraint (see, Gertler and Karadi (2011); Gertler and Karadi (2013)). Their leverage, Φ_t, is therefore constrained by their net worth, NW_t:

$$\tilde{\mathcal{Q}}_{I,t}\,B^p_{I,t+1}+\omega_L\,\mathcal{Q}_{L,t}\,B^p_{L,t+1}+\omega^*_{L,t}\,S_t\,\mathcal{Q}^*_{L,t}\,B^{*,p}_{L,t+1} \quad = \quad \Phi_t\,NW_t,$$

where $\tilde{\mathcal{Q}}_{I,t}$, $\mathcal{Q}_{L,t}$ and $\mathcal{Q}^*_{L,t}$ are the "discount prices" of the privately (p) intermediated assets $B^p_{I,t+1}$, $B^p_{L,t+1}$ and $B^{*,p}_{L,t+1}$ The capital position of banks thus influences the response of the economy to shocks via a financial accelerator mechanism. Incorporating adjustment costs into the pricing of loans, the model also includes the sluggish adjustment of lending rates.

Firms As regards firms, the model distinguishes between domestic producers of tradable intermediate goods and domestic producers of three types of non-tradable final goods: a private consumption good, a private investment good, and a public consumption good. The intermediate-good firms use labour and capital services as inputs to produce differentiated goods, which are sold in monopolistically competitive markets domestically and abroad. In doing so, they set different prices for domestic and foreign markets as a mark-up over their marginal costs. The final-good firms combine domestic and foreign intermediate goods in different proportions, acting as price takers in fully competitive markets. The foreign intermediate goods are imported from producers abroad, who set their prices in euro in monopolistically competitive markets, allowing for a gradual exchange-rate pass-through. A foreign retail firm in turn combines the exported domestic intermediate goods, with aggregate export demand depending on total foreign demand.

Besides the financial frictions described above, both households and firms face a number of nominal and real frictions, which have been identified as important in generating empirically plausible dynamics. Additional real frictions are introduced via external habit formation in consumption, through generalised adjustment costs in investment, imports and exports, and through fixed costs in intermediate-good production. Nominal frictions arise from staggered price and wage-setting as in Calvo (1983), in combination with (partial) dynamic indexation of price and wage contracts to past inflation.

Government The fiscal authority purchases the public consumption good, issues domestic bonds, and levies different types of distortionary taxes, albeit at constant rates; Ricardian equivalence holds because the fiscal authority's budget is balanced each period using lump-sum taxes.

Monetary policy Given our focus on monetary policy strategies, we describe the model interest rate rule, which we make use of in our initial counterfactual exercises of section 3. Specifically, the monetary authority is assumed to follow an inertial Taylor-type interest-rate rule targeting the response of inflation, the output gap, and their respective quarterly changes:

$$i_t \quad = \quad \rho\, i_{t-1} + (1-\rho)\, (\bar{r} + \bar{\pi} + \phi_{\hat{\pi}}\, \hat{\pi}_t + \phi_{\hat{y}}\, \hat{y}_t) + \phi_{\Delta\pi}\, \Delta\pi_t + \phi_{\Delta\hat{y}}\, \Delta\hat{y}_t + \eta_t \qquad (4)$$

The parameters of the interest-rate rule (see Table 1) are estimated on euro area data over the 1985:Q1-2019:Q4 period, using Bayesian methods.

Finally, the model is closed by a rest-of-the-world block, which is represented by a structural vector-autoregressive (SVAR) model determining five foreign variables: foreign demand, foreign prices, the foreign interest rate, foreign competitors' export prices and the price of oil.

Table 1: Taylor rule estimated parameters

	Variables	Posterior mode
ρ	Interest rate smoothing	0.9346
$\phi_{\hat{\pi}}$	Response to inflation	2.9334
$\phi_{\Delta\pi}$	Response to change in inflation	0.0361
$\phi_{\hat{y}}$	Response to output gap	0.0320
$\phi_{\Delta y}$	Response to change in output gap	0.0920

3 Counterfactual Monetary Policy Strategies

We assess how the euro area economy would have performed had monetary policy deviated from actual interest rate policy and considered a different starting period of its hiking cycle by following the model-consistent interest rate rule. We contrast these results against the predictions from an interest rate policy, which is designed optimally. We conduct both *ex post* and *real-time* assessments of various monetary policy approaches by changing the information set of the central bank in relation to its knowledge about future incoming data.

3.1 Macroeconomic projection baseline

A central element of our counterfactual experiments is the ECB / Eurosystem's staff projection baseline of euro area macroeconomic variables, and the extent to which agents in our model are aware of it. As part of the Eurosystem projection process (i.e. the Broad Macroeconomic Projection Exercises, or BMPE), such a baseline comprises quarterly paths for euro area real GDP growth, HICP inflation, and other macroeconomic aggregates. In particular, the official Eurosystem projection baseline is constructed using exogenous assumptions of the international economic environment, as well as an aggregation of national-level fiscal policies. Interest rates are assumed to follow the euro short-term rate (€STR) forward curve, making the baseline consistent with market-expectations of monetary policy conduct. These assumptions are combined together with additional off-model information, including expert judgment about the transmission and persistence of shocks.[2]

We treat such a projection baseline as an input into the model, for the purpose of rationalizing and projecting macroeconomic aggregates over the simulating horizon. Specifically, throughout the experiments we perform a series of model-based forecasts which condition on all structural shocks filtered from each baseline, other than the standard monetary policy shock.

Notably, our approach consists of evaluating the model-implied interest rate policy (either based on the estimated monetary policy rule or in an optimal manner) taking other policies and shocks as given. In particular, the structural shocks filtered from the baseline also contain information on the fiscal policy response, which is fully captured in the shock decomposition. As such, we abstract from the jointly optimal fiscal-monetary policy interaction. Moreover, the baseline for macroeconomic variables also incorporates the effects from other parallel monetary policies involving other instruments that were also implemented from 2022 onwards, such as the termination of

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[2] More detailed illustrations of the use of NAWM II for forecasting and policy analysis can be found in Ciccarelli et al. (2024).

net asset purchases in 2022:Q3, the introduction of the Transmission Protection Instrument (TPI) to support the effective transmission of monetary policy across countries, and the recalibration of Targeted Longer-term Refinancing Operations (TLTRO) III.

3.2 Timing of the hike: what if the ECB followed the estimated Taylor rule?

We place ourselves in 2021:Q4, 2022:Q3, or 2024:Q1 and assume full knowledge of incoming data and the Eurosystem's staff off-model baseline forecast from the December 2023 projection.[3] We then determine the interest rate path, as well as the associated macroeconomic allocation, that would be consistent with the historical monetary policy reaction function as implied by our model.

The rule-based projection is implemented by performing a conditional forecast and conditioning on all structural shocks filtered from the December 2023 baseline, other than the standard monetary policy shock. This allows taking into account all non-monetary structural shocks, that, according to the model, had hit or we were expected to hit the economy between the starting date of the counterfactual simulation and 2026:Q4, including global supply shocks, energy and food price shocks and the tightening of the labour market. To the extent that the estimated rule of the model is a good approximation of market expectations about ECB interest rate policy, deviations of historical and forward interest rates from the rule-based projection would reflect the discretionary component of monetary policy interventions.

Figure 1 depicts the rule-based policy counterfactuals whereby the ECB ended its lower-for-longer policy and followed the historical reaction function since 2021:Q4 (solid light blue lines), 2022:Q3 (dashed light blue lines), or extended the lower-for-longer policy until 2023:Q4 (dotted light blue lines), compared with historical data and baseline projections (solid dark blue lines).

Had the ECB followed the rule-based policy in 2021:Q4, it would have hiked the short-term interest rate immediately, reaching a level of 3.75% in 2022:Q4 which it would maintain roughly until end 2025. Compared to actual policy, the counterfactual tightening impulse would have initially slowed down GDP growth more markedly and the euro area economy would have been in a recession in 2022 and the first half of 2023. Annual HICP inflation, in turn, would have been lower, peaking around 8% instead of 10% in the end of 2022 due to the sharp slowdown in economic activity. Relative to the baseline, inflation would have reached the 2% target 8 quarters earlier, in 2024:Q1 and been projected to settle below the target in 2025.

Instead, if the lower-for-longer period ended in 2022:Q3 (dashed light blue lines) — in line with actual policy conduct — and the model-consistent rule-based policy was followed thereafter, the interest rate hikes would have been somewhat higher than in the actual policy path until 2023:Q1, but with more gradual tightening thereafter, only reaching a peak of 3.75% in 2024:Q2. The profile of this rule-based policy projection indicates that the actual hiking cycle can be divided into two phases: first, a swift normalization of policy rates to prevent a protracted decline in real interest rates from boosting demand and fueling additional inflationary pressures; second, gradual adjustments towards the peak rate and a restrictive stance to further anchor expectations at the

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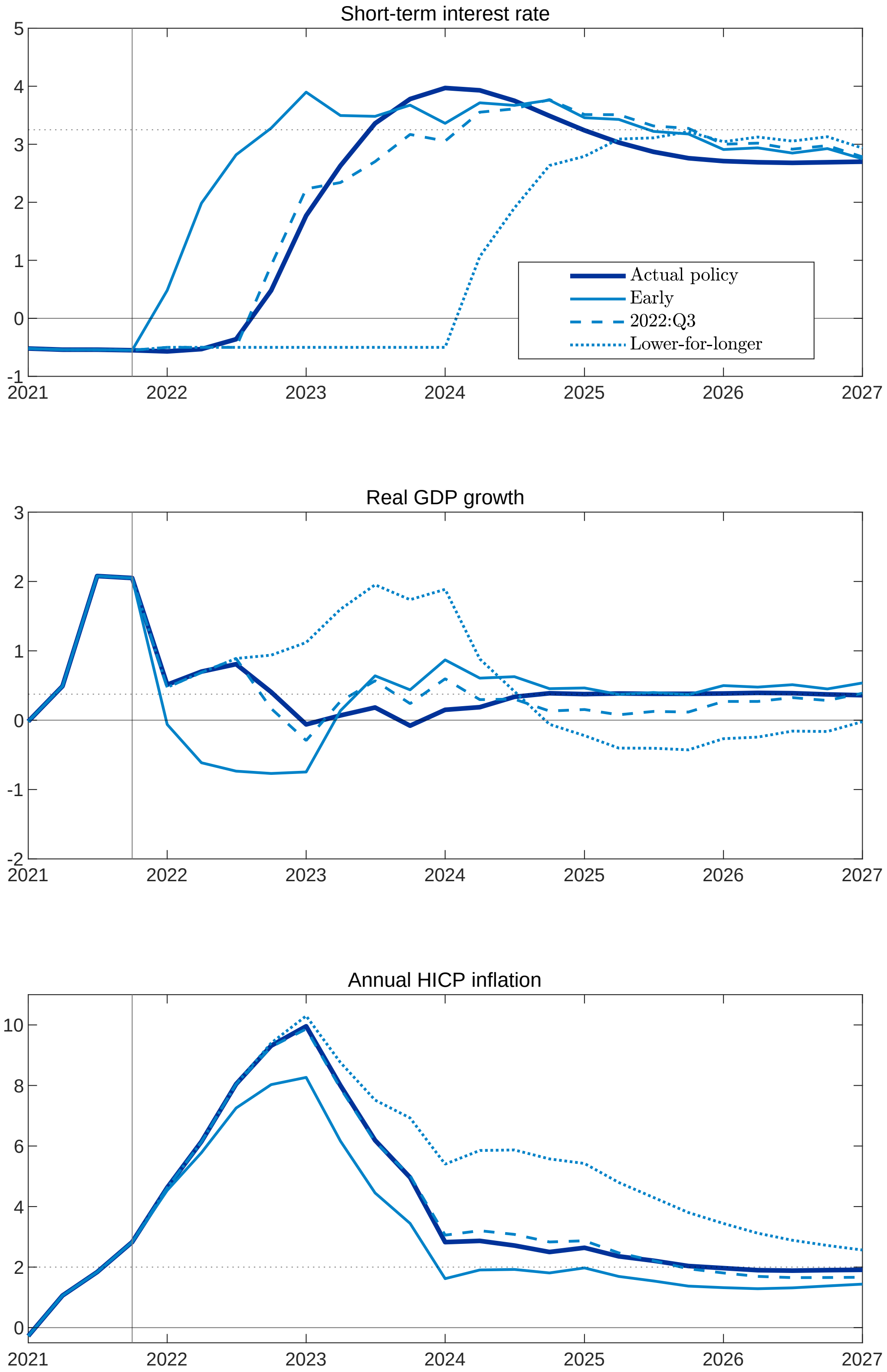
[3] In Section 3.4 we relax the assumption of full information and repeat the exercise in real-time, whereby in each period only the contemporaneous vintage of each baseline is known.

Figure 1: Rule-based counterfactuals in 2021:Q4, 2022:Q3, and 2024:Q1



Note: This figure depicts rule-based counterfactual policies whereby the ECB follows the NAWM policy rule since 2021:Q4 (solid light blue lines), 2022:Q3 (dashed light blue lines) or 2024:Q1 (dotted light blue lines), conditioning on the data and macroeconomic outlook from Eurosystem's staff projections in December 2023 (solid dark blue lines).

2% target. The effects under this policy counterfactual suggest that the economic slowdown would have been short lived — after a quarter below zero, GDP growth would have rebounded more markedly in 2023:Q2 — with similar disinflationary process as in the baseline for 2023 but higher inflation in 2024 by 0.3 percentage points. The convergence to the 2% target would be reached by end-2025 as in the baseline.

Last, we contrast the effects of these policies against the counterfactual whereby the lower-for-longer policy is maintained until 2023:Q4 (dotted light blue lines) before following the model-consistent rule-based policy from 2024:Q1 onwards. The counterfactual can be interpreted as the strongest form of "looking-through" the full sequence of supply shocks, leaving policy rates unchanged until the beginning of 2024. In this counterfactual, the lack of monetary tightening would have pushed output significantly above potential between 2022:Q2 and 2025:Q1 and led to higher inflation expectations, more pronounced second-round effects, and thus higher and more persistent price inflation, peaking around 10.5% and remaining above 4% until 2026.

Overall, the results suggest that with full information about the macroeconomic conditions that would prevail since 2021, an earlier hike would have reduced the peak of inflation and achieved convergence to the target faster, but would have driven the euro area economy into recession all through 2022. However, the 2022:Q3 counterfactual exercise demonstrates that, once aligning the interest rate lift-off date with actual policy conduct, the counterfactual monetary tightening would be broadly similar to the baseline in terms of inflation and interest paths. From this standpoint, the estimated interest rate rule of the NAWM II tracks relatively well the tightening cycle observed from 2022:Q3 to 2024:Q1. Keeping interest rates unchanged for longer, as in the 2024:Q1 counterfactual, would lead to higher inflation rates becoming entrenched with significant second-round effects materialising over the medium term.

3.3 What would optimal interest rate policy prescribe?

While conditional forecasts using the model-consistent interest rate rule enable assessing the effects of different starting points for the hiking cycle, a natural question that arises is whether these counterfactual monetary policy strategies are optimal from a loss function minimization perspective.

To address this, we compute optimal policy counterfactuals—at various starting dates—under commitment and conditional on the December 2023 macroeconomic baseline and a standard central bank loss function. We assume that the central bank commits *ex ante* to setting the short-term interest rate to minimize a quadratic loss function that approximates household utility, penalizing deviations of inflation from target, output from potential, and excessive interest rate volatility.

The approach builds on the concept of optimal policy projections under commitment, first introduced by Svensson (2005), who formalized the selection of alternative paths for target variables and policy instruments to minimize a central bank's loss function. It was first applied in practice using the Fed's FRB/US model by Svensson and Tetlow (2005), and is closely related to the targeting rule framework for optimal policy by e.g., Svensson and Woodford (2003). Specifically, among the set of alternative projections that shift the target and policy variables away from baseline paths using anticipated and unanticipated impulse responses to the policy instrument, the method relies on identifying the projection that minimizes the policymaker's objective function. In our implementation, we use the COPPs toolkit of de Groot et al. (2021) in Dynare (Adjemian et al.

(2022)). Notably, complementary methods have been proposed by Barnichon and Mesters (2023) who show that the gradient of the central bank's loss function in response to policy shocks is a sufficient statistic for capturing the optimal policy, but also McKay and Wolf (2023) who leverage sequence-space representations of equilibria to show that in linearized structural macroeconomic models, the impulse responses to policy news shocks are sufficient to construct policy rule counterfactuals. Carrier and Mavromatis (2024) extend the methods to a behavioral model whereby exepctations may become de-anchored.

Our assumed loss function follows the standard specification found in the optimal monetary policy literature (see, e.g., Giannoni and Woodford (2003), Woodford (2010), Debortoli et al. (2019)), or Harrison and Waldron (2021). Formally, the loss for strategy j, between t and $t+h$ is defined by:

$$\mathcal{L}_j = \frac{1}{2}\sum_{t}^{t+h} \beta^t \mathbb{E}_t(\lambda_\pi \hat{\pi}_{t,j}^2 + \lambda_y \hat{y}_{t,j}^2 + \lambda_{\Delta i}\Delta i_{t,j}^2) \tag{5}$$

where β is the discount factor, $\hat{\pi}$ is the difference between inflation and the inflation target, $\hat{y}$ is the percent deviation of output from its potential and Δi is the quarterly change in the short-term nominal interest rate.

The relative weights attached to inflation, output and rate stabilization can be interpreted as reflecting central bank policy preferences. Being agnostic on these values, we calibrate them such that the "benchmark" optimal policy projection starting in 2022:Q3 implies a short-term rate whose path approximates the baseline path of the euro short-term rate (€STR) forward curve. A more "hawkish" loss function would then require a lower weight on output stabilization.[4] Starting from a value of $\lambda_\pi = 1$, the benchmark calibration yields $\lambda_y = 0.5$ and $\lambda_{\Delta i} = 4$. Our "hawkish" calibration considers a stronger focus on price stability with a lower weight on output $\lambda_y = 0.1$. [5]

Figure 2 depicts optimal policy counterfactuals at different points in time and under both the "benchmark" and "hawkish" central bank preferences. Compared to the estimated interest rate rule-based counterfactural, optimal policy counterfactuals are more hump-shaped, with higher peak rates but less persistence of the restrictive stance. The benchmark preferences would engineer a mild recession and would deliver inflation outcomes by 2024 and 2025 quite similar to the baseline. Instead, more hawkish preferences would engineer a deeper recession and be associated with a faster disinflationary process followed by a mild undershooting of the target in 2024.[6]

Specifically, the optimal policies announced in 2021:Q4 (solid red or yellow lines) prescribe

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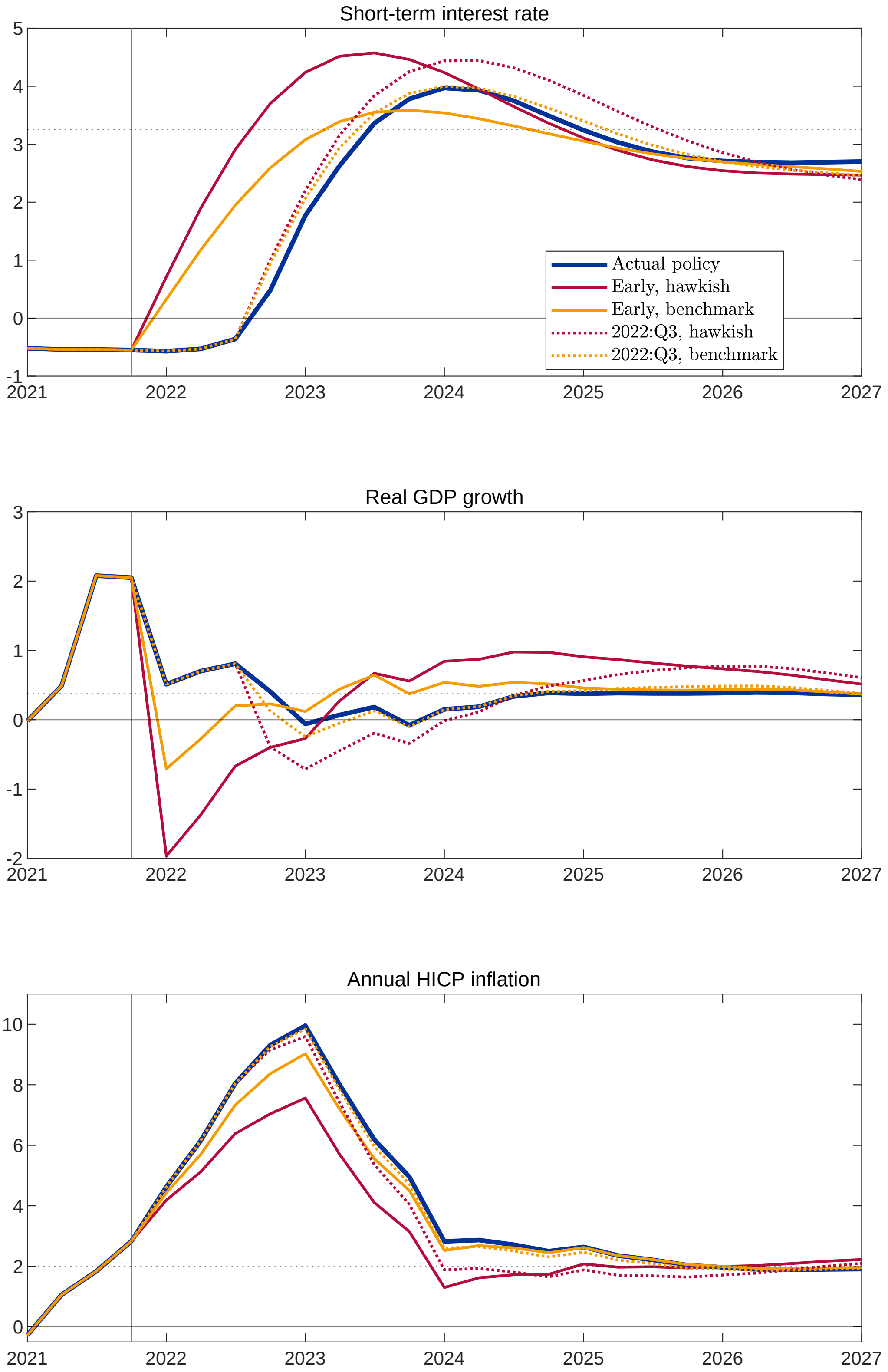
[4] As with the rule-based policy counterfactual, we assume that the policymaker adjusts only the short-term interest rate, while central bank balance sheet runoffs proceed in line with market expectations and their effects are included in the macroeconomic projection baseline. Similarly, we abstract from the jointly optimal determination of monetary-fiscal policy and take fiscal policy as given with its effects being incorporated into shaping the macroeconomic baseline.

[5] Note that in section 4.1, we perform more general sensitivity analysis around the relative weights attached to the output gap, λ_y, and interest rate smoothing, $\lambda_{\Delta i}$, which allows computing a range of optimal policy projections under the constellation of policy preferences consistent with medium-term price stability.

[6] Given the hump-shaped nature of the optimal interest rate paths, Appendix A.1 extends the analysis and compares the optimal policy outcome under alternative average inflation targeting (AIT) frameworks. Relatedly, in section 3.5 we illustrate how the optimal policy can be implemented by optimising on the coefficients of the interest rate rule of the NAWM II, following the approach in Schmitt-Grohe and Uribe (2007).

Figure 2: Optimal policy projections in 2021:Q4 and 2022:Q3



Note: This figure depicts counterfactual optimal policy projections at different points in time, under alternative parameterizations of the central bank loss function and conditioning on the data and macroeconomic outlook from Eurosystem's staff projections in December 2023. Solid red (yellow) lines represent the optimal policy in 2021:Q4 with hawkish (benchmark) preferences. Dotted red (yellow) lines represent the optimal policy in 2022:Q3 with hawkish (benchmark) preferences.

hiking the policy rate gradually from -0.5% in 2021:Q4 to between 3.5% and 4.5%, respectively in the period 2023:Q2-2023:Q4. The peak rate is lower and is reached later in 2023 if the output weight in the loss function is high (solid yellow lines) whereas it is higher and reached earlier in 2023 if the output weight is smaller (solid red lines). At the same time, optimal policy with hawkish preferences generates a significant disinflation and implies rate cuts already in mid-2023 to avoid a sharp undershooting of inflation. Optimal policy with benchmark preferences, in turn, would necessitate a lower but more persistent peak rate. In the two optimal policies, the early start of the hiking cycle achieves to limit the peak of inflation but at the expense of more severe downturn in GDP growth.

In turn, when optimal policy is implemented in 2022:Q3 (dotted red and yellow lines), the paths for the policy rate are less gradual and their peaks range between 4% and 4.25% reflecting that the higher inflation rates have already materialised at the time of policy shift. By calibration design, the benchmark optimal policy implies a similar interest rate path as in the baseline but achieves marginally lower inflation rates all through the simulation horizon, at the cost of lower GDP growth rates for few quarters in the turn of 2023 (dotted yellow line). The proximity of the benchmark optimal policy macroeconomic outcomes with the baseline, once assuming the 2022:Q3 lift-off date, brings further indication that the actual policy conduct managed to implement an efficient management of the output-inflation trade-off. By comparison, the rate hikes under the hawkish optimal policy, given the later start of the hiking cycle, would peak above 4% and remain persistently in restrictive territory (dotted red line). This would be sufficient to bring inflation back to target by 2024:Q1 but at the expense of a more pronounced and persistent reduction in GDP growth relative to baseline.

3.4 Monetary policy in real time: bad luck or bad policy?

The medium-term orientation of monetary policy implies a forward-looking approach that relies heavily on the economic outlook, making accurate macroeconomic projections essential for effective policy calibration. In reality, however, unforeseen macroeconomic shocks often lead to forecast errors and, consequently, suboptimal policy decisions when judged *ex post*. A prominent example is the Russian invasion of Ukraine in 2022:Q1, which triggered lasting supply disruptions and a surge in energy prices. Had the ECB foreseen this event and its economic consequences back in December 2021, an earlier interest rate hike may have been warranted.

We now simulate policy counterfactuals in real-time to assess the respective role of "bad luck" (i.e. one-sided repeated adverse shock hitting the euro area economy) and "bad policy" (i.e. delayed monetary tightening or suboptimal management of the output-inflation trade-off) in shaping macroeconomic outcomes since 2022:Q1. In this setting, policy counterfactuals are updated each quarter between 2021:Q4 and 2023:Q4, reflecting new vintages of incoming data and macroeconomic projections. This exercise illustrates how policy projections are revised quarter after quarter as new shocks hit the economy over that period.[7]

Figure 3 illustrates the comparison between actual policy and a real-time staggered policy

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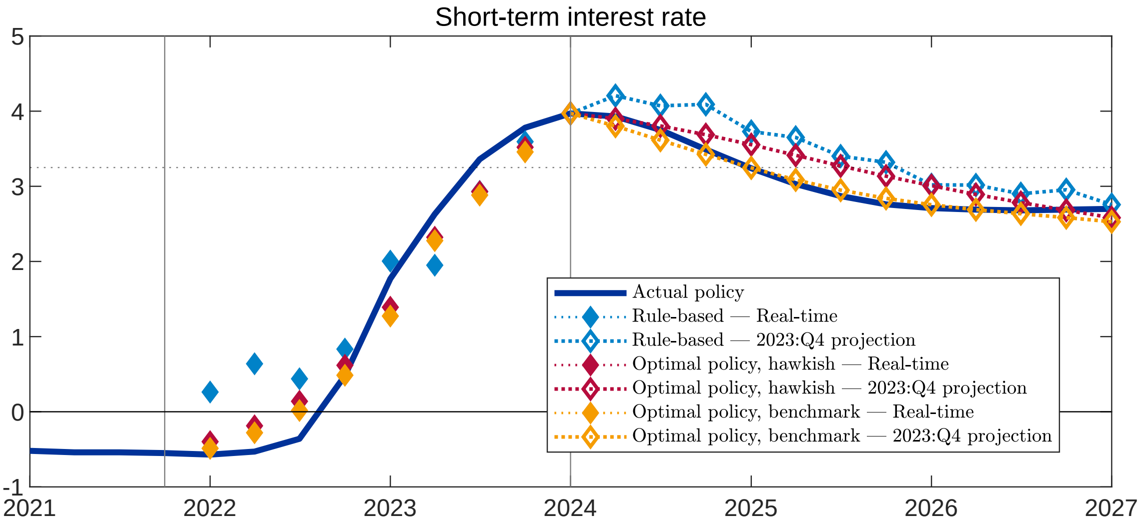
[7] The importance of real-time data for estimating monetary policy rules and evaluating the effectiveness of monetary policy is also described in Orphanides (2001), Molodtsova et al. (2008), and Altavilla and Ciccarelli (2011), among others.

setting, using either the interest rate rule of the model (blue diamonds), or optimal policy with hawkish (red diamonds) and benchmark (yellow diamonds) preferences.[8] The staggered nature of the simulated policy paths reflects changes in the economic outlook, market expectations for the interest rate path, and the implied optimal policy response in each quarter.

Figure 3: Staggered real-time policy from 2021:Q4



Note: This figure depicts policy under staggered real-time information about macroeconomic conditions between 2021:Q4 and 2023:Q4. Rate prescriptions are updated every quarter by conditioning the policy projections on the most recent vintage of staff projections at the time (December 2021, March 2022, June 2022, September 2022, December 2022, March 2023, June 2023, September 2023, December 2023) instead of the realized values of macroeconomic variables. The policy is thus set optimally according to the best available forecast at the time but may be sub-optimal ex post as unexpected shocks hit the economy. The staggered rule-based policy prescriptions are computed and updated each quarter by finding the policy path that is consistent with the feedback rule of the model while the optimal policy paths are computed by minimizing the central bank inter-temporal loss function.

The real-time projections suggest that rate hikes could have started in the first half of 2022 and take the policy rate to 4% 2024:Q1. Actual rate hikes instead started in 2022:Q3 and took the policy rate to 4% in 2023:Q3. However, unlike simulations with full information about the sequence of shocks hitting the economy, in real time there is no rationale for hiking policy rates aggressively already in 2022:Q1.

Overall, the real-time simulations confirm that actual policy fares relatively well against alternative policy conducts. In particular, the actual rate path aligns more closely with real-time optimal policy projections than with the model's estimated interest rate rule. Optimal policy projections in real time from 2021:Q4 indicate a slower tightening compared to what the model's interest rate rule would suggest. However, both real-time rule-based and optimal policy prescriptions still imply an earlier lift-off date, although not as steep as the actual rate path. While policy rates normalisation appears to have been delayed in comparison to these real-time projections, the steeper hiking profile has at least partially counterbalanced the initial easing impulse.[9] From 2024

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[8] Figures A.2 and A.3 (in the Appendix) show the quarter-by-quarter projection baselines for interest rates, real GDP growth, and HICP inflation, as well as projections from the corresponding policy counterfactuals.

[9] The ECB initiated the tightening cycle with a 50 basis points hike in July 2022, followed by two 75

onwards, counterfactual policy projections point to policy rates above market expectations, with the exception of the benchmark optimal policy, which closely aligns with the forward curve.

3.5 Optimised simple rules

Our set of experiments so far has focused on simulating counterfactual rule-based policies and performing counterfactual optimal policy projections. In this next experiment we aim for a middle ground of deriving the optimised simple rule (OSR) (as in Schmitt-Grohe and Uribe (2007)) which enables to find the optimised coefficients for the monetary policy rule in our large-scale NAWM II. Specifically, we search for the set of parameters in eq. 4 that minimise the welfare loss function from eq. 5, that is the variance of (annual) HICP inflation, the output gap, and interest rate volatility, given the other estimated parameters and dynamic properties of the model. In this way, we achieve to identify a tractable and transparent policy rule that closely approximates the outcomes of fully optimal policy under commitment, while being more implementable and robust to model uncertainty.

Table 2 provides the coefficients from the optimized simple rules based on the specification of the NAWM rule. Column "benchmark" considers the case where the loss function assigns a weight on output that is half of that on price inflation, whereas column "hawkish" minimizes the coefficients relative to a loss function which assigns a weight on output that is 10% of that on inflation. Column "NAWM" reports the results from the estimated model.

Table 2: Optimised benchmark and hawkish policy rules

	Variables	**NAWM**	**Benchmark**	**Hawkish**
ϕ_R	Interest rate smoothing	0.9346	0.9993	0.9988
ϕ_π	Response to inflation	2.9334	183.2040	195.8903
ϕ_Y	Response to output gap	0.0320	8.4097	1.4462
$\phi_{\delta\pi}$	Response to change in inflation	0.0361	-0.1736	-0.1134
$\phi_{\delta Y}$	Response to change in output gap	0.0920	0.3235	0.1826

Note: The parameters of the optimized simple policy rules are calculated to minimize the variance of annual HICP inflation, the output gap and the policy rate, given the other estimated parameters and dynamic properties of the model. The "benchmark" optimized rule assigns a weight on output that is half of that on price inflation, whereas the "hawkish" optimized rule assigns a weight on output that is 10% of that on inflation.

Taking into account the set of optimised coefficients, the hawkish rule assigns a greater weight to inflation stabilization than the estimated NAWM rule, consistent with its definition of the loss function, which places 90% of the policy weight on inflation relative to output. The benchmark rule features a sizable coefficient on the output gap, consistent with a more balanced policy stance——specifically, output receives half the weight of inflation in the loss function. In contrast, the hawkish rule assigns a much smaller response to output, reflecting the diminished importance of output stabilization. Both the benchmark and hawkish rules imply high interest rate smoothing parameters (close to 1), reflecting a strong preference for gradualism in policy adjustments. This smoothness helps reduce policy-induced volatility and supports macroeconomic stability by avoiding abrupt

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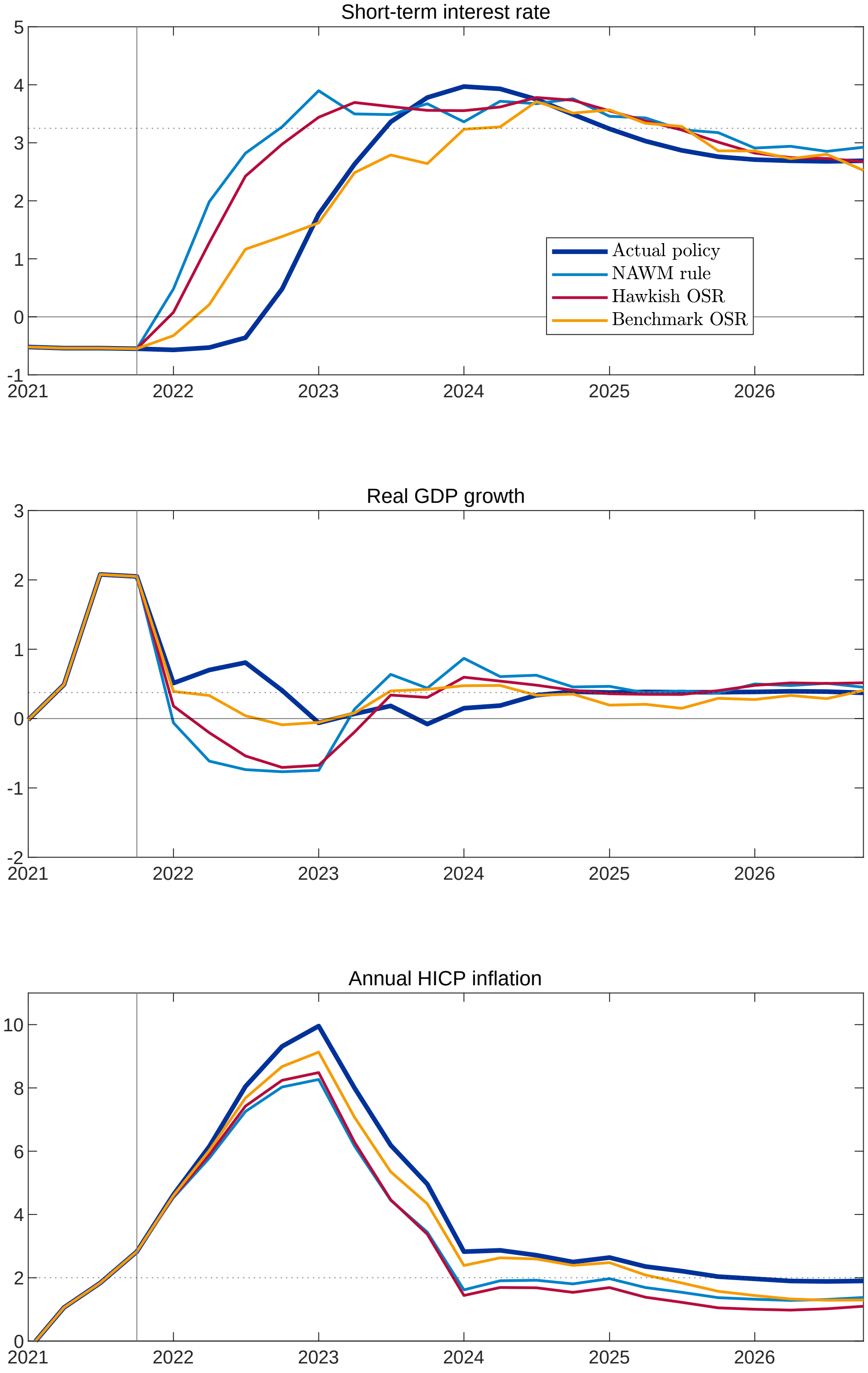
basis points hikes in the subsequent policy meetings. Lane (2023) shows that the scale and speed of the adjustments stand out in the history of the monetary union.

changes in the policy stance. Finally, the original policy rule allows for the stabilization over the changes in inflation and the change in the output gap. The small and slightly negative coefficients on the change in inflation in the OSR suggest that the rule modestly dampens overreaction to short-run inflation movements, acting as a stabilizer against transitory fluctuations. The negative coefficient is interpreted as a corrective force, reducing the amplification of temporary inflation shocks. The optimised coefficients also suggest a moderate response to the change in the output gap, again enhancing the rule's responsiveness to the economic cycle without overreacting to temporary changes. The benchmark rule places a higher weight on this term than the hawkish one, consistent with the former's stronger emphasis on real-side stabilization.

Figure 4 simulates the rule-based policy counterfactual projections in 2022:Q3 based on optimized coefficients and compares their prescriptions against the corresponding (estimated) rule-based projection. As with the rule-based projection, the counterfactual macroeconomic outcomes in the OSR-based projection are computed by re-simulating the filtered projection baseline, taking actual policy deviations from the rule as unanticipated monetary policy shocks. The only difference across the set of rules therefore arises from the alternative parameterization of the coefficients.

Our results suggest that the hawkish optimized simple rule performs similarly to the estimated policy rule, prescribing a similar increase in the policy rate and of the same duration for achieving a marginally larger decrease in inflation from baseline in the medium term. Instead, the "benchmark" optimised simple rule—which attaches a higher weight to output gap stabilization—prescribes a more gradual increase in the policy rate, which on the hand closes the output gap faster but at the expense of a slower convergence of inflation to target.

Figure 4: NAWM rule against optimized simple rules



Note: This figure depicts counterfactual policy projections conditioning on the data and macroeconomic outlook from Eurosystem's staff projections in December 2023 (solid dark blue lines). Solid light blue lines represent the NAWM rule-based policy projections. Solid red (yellow) lines represent the optimal simple rules projections in 2021:Q4 with optimized coefficients under a minimization of the loss function consistent with hawkish (benchmark) preferences.

3.6 Stabilisation metrics

Given the various monetary policy strategies evaluated so far, we provide synthetic indicators of macroeconomic volatility and welfare implied by each strategy. Our focus is on measuring the deviation of relevant variables x from their respective targets $\bar{x}$ over the period 2022:Q1-2026:Q4. For each monetary policy strategy j, our metric of *ex post* macroeconomic stabilisation is defined as the square root of the sum of discounted squared deviations of inflation, the output gap and quarterly changes to the policy rate from their target levels, 2%, 0%, and 0% respectively:

$$\mathcal{V}_j = \sqrt{\sum_{t}^{t+h} \beta^t \mathbb{E}_t (x_{t,j} - \bar{x})^2} \tag{6}$$

For the evaluation of *real-time* strategies, we take the average over n quarterly macroeconomic and policy projections vintages of the square root of the sum of squared deviations of inflation, output gap and quarterly changes to the policy rate from their target levels:

$$\tilde{\mathcal{V}}_j = n^{-1} \sum_{n} \sqrt{\sum_{t}^{t+h} \beta^t \mathbb{E}_t (x_{t,j} - \bar{x})^2} \tag{7}$$

Separately, we also report the welfare loss from each strategy, consistent with equation 5, to assess to what extent various strategies affect consumer utility.

Table 3 illustrates the results. Columns (1) to (3) present the volatility of inflation, the output gap and the policy rate, while columns (4) and (5) show the associated welfare loss under alternative calibrations of the loss function.

Starting with the *ex post* evaluation of the alternative monetary policy strategies, they all improve on the stabilisation of inflation relative to actual policy, with the notable exception of the lower-for-longer (LFL) policy where the hiking cycle is initiated in 2024:Q1. Earlier policy tightening and the hawkish optimal policy conduct would deliver the most significant dampening of inflation volatility. Optimal policy with hawkish preferences, in particular, lowers inflation volatility by 32% with earlier interest rate lift-off relative to actual policy. However, these inflation stabilisation benefits, whether initiated in 2021:Q4 or 2022:Q3, are associated with higher output volatility. Considering the early implementation case, the output volatility is increased from 3- to 10-fold across the optimal and rule-based policy conduct.

In order to assess such alternative management strategies of the output-inflation trade-off, the measures of loss functions (for both benchmark and hawkish preferences) are reported in Table 3, for all policy configurations. Assuming the *ex post* simulation protocol, it appears that the benchmark optimal policy outperforms actual policy, whatever the loss function is used in the evaluation. However, a concomitant implementation of the benchmark optimal policy does not allow significantly outperforming the baseline. The rule-based policy generally delivers worse outcomes, except in the early tightening case for the loss function with the hawkish preferences. Notably, the rule-based policy, when implemented as of 2022:Q3, has a similar performance to the actual policy across all metrics. The hawkish optimal policy only improves the loss function with the hawkish preferences (against which the policy conduct is optimised): this policy would be

Table 3: Macroeconomic volatility and welfare with alternative strategies

	Volatility			Welfare loss	
	Inflation	Output	Policy rate	Bench.	Hawkish
Ex post with full information					
Actual policy	1.00	1.00	1.00	1.00	1.00
Rule-based policy:					
early	0.79	8.09	1.14	1.15	0.76
2022:Q3	1.00	0.97	1.06	1.01	1.01
2024:Q1 (LFL)	1.24	12.68	0.97	2.71	1.74
Optimal simple rules:					
early, benchmark	0.90	3.01	0.87	0.87	0.82
early, hawkish	0.83	7.99	0.98	1.17	0.79
Optimal policy under commitment:					
early, benchmark	0.87	3.66	0.85	0.85	0.78
early, hawkish	0.68	10.06	1.16	1.25	0.66
2022:Q3, benchmark	0.98	1.90	1.04	0.99	0.97
2022:Q3, hawkish	0.94	5.07	1.14	1.10	0.95
Staggered, real-time information					
Actual policy	1.00	1.00	1.00	1.00	1.00
Rule-based policy	1.00	1.99	1.16	1.09	1.02
Optimal policy, benchmark	0.99	1.30	0.96	0.99	0.98
Optimal policy, hawkish	0.97	1.94	1.02	1.04	0.97

Note: The figures are provided relative to actual policy over the 2022:Q1-2026:Q4 period: a value above (below) 1 indicates a higher (lower) variance of the policy target variable in the policy counterfactual relative to actual policy. For instance, a value of 0.9 indicates a 10% improvement in the stabilization of the policy target variable. Benchmark preferences: $\lambda_\pi = 1$, $\lambda_y = 0.5$, $\lambda_{\Delta i} = 4$. Hawkish preferences: $\lambda_\pi = 1$, $\lambda_y = 0.1$, $\lambda_{\Delta i} = 4$.

ranked even worse than the rule-based policy, on the basis the benchmark loss function. Finally, the LFL policy underperforms markedly because looking through the sequence of shocks leads to higher and above-target inflation for at least three more years and to a prolonged recession once the policy tightening eventually materialises in the course of 2024, lasting at least twice as long as the recession in the early-tightening scenario.

Turning to the real-time stabilisation metrics between December 2021 and December 2023 (last rows of Table 3), the inflation stabilisation or welfare improvements of the optimal policies become smaller. The benchmark optimal policy can still yield some benefits but they remain below 2% for inflation volatility or the loss functions. The hawkish policy only improves welfare if preferences are indeed hawkish.

To summarise, the review of the various stabilisation metrics broadly supports the effectiveness of the actual policy conduct since 2021:Q4. However, it is important to acknowledge that the validity of these counterfactual results and their welfare evaluation is inherently tied to the assumptions underlying the model. In particular, the analysis employs a first-order approximation to capture the model's dynamics. Given the sizable shocks during the episodes under investigation, certain nonlinearities may not be fully captured, which could result in less persistent effects or muted responses, thereby understating the welfare losses associated with different strategies. Additionally, the model assumes that longer-term inflation expectations remained anchored throughout the period of investigation. While reasonable in retrospect, this assumption could influence the results by dampening the potential feedback effects on inflation dynamics and hence welfare, especially under conditions of heightened uncertainty (Carrier and Mavromatis, 2024).

4 Robustness

As the validity of the findings presented so far is based on key model assumptions, there is considerable uncertainty around several aspects of our analysis. In what follows, we focus on disciplining this uncertainty around three key dimensions: i) the specification of policymaker preferences in the central bank's loss function, ii) key parameters of the model that affect the transmission of shocks through the production structure and the financial sector, and iii) private sector expectation formation mechanisms.

4.1 Policymaker preferences

The calibration of the loss function utilised so far for optimal policy represent policymaker preferences that range from a balanced dual mandate approach ("benchmark") to a "hawkish" environment. To assess the robustness of our results to policymaker preferences we extend this range of central bank preferences by computing, for a given relative weight of the price stability coefficient ($\lambda_\pi = 1$), the set of parameters λ_y and $\lambda_{\Delta i}$ which deliver inflation of 2% in 2025 or 2026. We do so both for a hiking cycle which is initiated in 2021:Q4 as well as in 2022:Q3.

Figures 5 illustrates the effects from the range of strategies delivering target-consistent inflation in 2025 (yellow area) and 2026 (red dashed line) when initiating the optimal hiking cycle in 2021:Q4 (left column) or 2022:Q3 (right column). These strategies encompass a constellation of policy preferences with respect to macro-financial volatility considerations while projecting desired inflation outcomes.[10] Several target-consistent strategies exist, and therefore price stability in 2025 can be achieved optimally with a lower smoothing parameter, especially when combined with a

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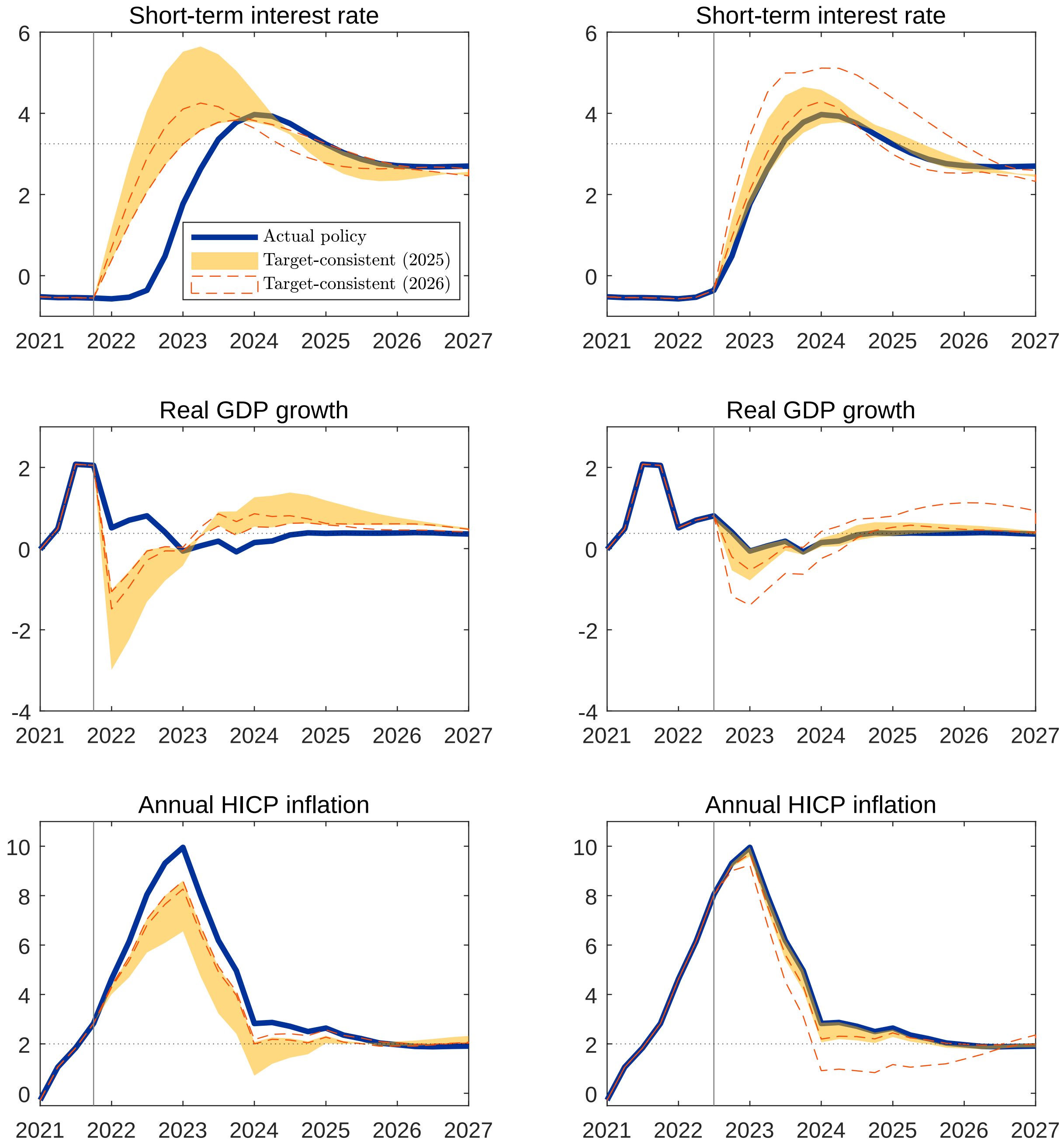
[10] Figure A.4 in the Appendix presents the combinations of preferences (calculated over λ_y and $\lambda_{\Delta i}$) for which an optimal policy is consistent with price stability in the medium term for various policy horizons, 2025 and 2026, respectively. Starting in 2021:Q4 and considering a three-year horizon, there is a positive relationship between the weight assigned to output λ_y and the interest rate smoothing parameter $\lambda_{\Delta i}$, indicating that considerations for inflation-output trade offs must be associated to more gradual changes to interest rates. Instead, postponing the hiking cycle start results in a shorter policy horizon and requires a more moderate tightening impulse to mitigate the risk of falling below the inflation target in 2025. For price stability over a longer horizon, there is a negative relationship between λ_y and $\lambda_{\Delta i}$ implying that a lower weight on output necessitates higher rate smoothing to increase persistence at the peak level and prevent overshooting the inflation target.

lower weight on output stabilisation. Conversely, additional weight on output stabilisation is associated with smoother policy. The resulting optimal paths ranges are in the ballpark with those obtained from the simulations under our two main loss functions.

Figure 5: Optimal policy projections with inflation target-consistent strategies



A. Initiated in 2021:Q4

B. Initiated in 2022:Q3

Note: This figure depicts the optimal counterfactual policy projections conditioning on the data and macroeconomic outlook from Eurosystem's staff projections in December 2023 (solid blue lines). The loss function (eq. 5) is parametrized using the range of parameters contained in the white isocurves of Figure A.4, that deliver target-consistent inflation in 2025 (yellow area) and 2026 (red dashed lines).

Target-consistent optimal policy projections, computed for a constellation of policy preferences, depend on the policymaker's choice for the lift off date and the policy-relevant horizon. When the rate lift off is initiated already in 2021:Q4, optimal policy frontloads rate hikes to slow down economic activity and obtain a lower peak of inflation in 2022 and ensure a rapid disinflation process. If the policymaker targets inflation in 2025, this may result in some undershooting of the target in 2024, while targeting inflation in 2026 would result in a convergence towards the target from above. Delaying the lift off to 2022:Q3 reduces the scope to impact inflation in 2022 and 2023. To improve over the baseline, optimal policy requires a steeper rate path but a somewhat lower peak compared to the policy initiated in 2021:Q4. If inflation must be at the target in 2026 (and not in 2025), optimal policy is to tighten more to reduce inflation while allowing some undershooting in 2025 before the target is reached from below in 2026.

4.2 Parameter uncertainty

Next, we undertake robustness checks around key parameters of the model that dictate the transmission of shocks through the production structure and the financial sector. For consistency with previous experiments, we focus on optimal policy counterfactuals. Figure 6 illustrates the optimal policy starting in 2021:Q4 under a steeper slope of the price Phillips curve (dashed green line), higher households' portfolio adjustment costs (dotted light blue lines), higher degree of wage indexation (dashed purple lines), and lower investment adjustment costs (dashed red line) contrasting them against our benchmark (solid yellow lines).[11]

Slope of the price Phillips curve The slope of Phillips curve is one of the parameters of the model that is originally estimated using Bayesian methods and therefore subject to some degree of parametric uncertainty. All else equal, a steeper Phillips curve implies that price inflation is more responsive to changes in economic activity, and therefore a tightening impulse can induce greater disinflation for a given impact on output and employment, and hence a more favourable sacrifice ratio (Tetlow (2022), Ciccarelli et al. (2024)).

To quantitatively assess this channel, we set the Calvo parameter ξ_H to 0.7, below the posterior mode of 0.82. In this version of the model, the probability that firms receive permission to optimally reset the price of the output sold in the domestic market is higher. As policy faces a lower sacrifice ratio, a higher policy rate is the optimal policy: under this configuration, higher policy rates would significantly dampen inflationary pressures with a limited additional fall in output, as also shown by Karadi et al. (2024).

Strength of financial frictions The households' portfolio adjustment cost γ_L^h is a key parameter governing the behaviour of households and the overall degree of financial frictions in the model. Households hold a portfolio of short-term and long-term government bonds and any changes to its composition is subject to adjustment costs. The demand for the long-term bond therefore depends on the present value of excess bond returns relative to short-term bonds (i.e. an interest

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[11] These sensitivity exercise also capture instances of possible non-linearities reflecting e.g., a state-dependent Phillips curve or non-linear wage-price effects and hence a different transmission of shocks in high-inflation regimes (see, e.g., De Santis and Tornese (2023).

rate premium), which is increasing with an elasticity equal to the inverse of the adjustment cost parameter. As γ_L^h increases, the demand elasticity falls and households respond less flexibly to changes in excess bond returns. Overall, the degree of portfolio adjustment costs amplifies the effects of shocks in the model when the financial intermediary balance sheet constraint tightens and the premium of long-term government bond increases.

We increase the households' portfolio adjustment cost to an upper bound of $\gamma_L^h = 0.30$ instead of the estimated value of $\gamma_L^h = 0.007$. A higher value would hence amplify the response of economic activity to a monetary policy shock, as an increase in the interest rate would lead to a reduction in demand for long-term financing from the households–by raising excess bond returns by more–which lowers investment, consumption, and output overall. As a result, in an economy with a higher degree of financial frictions, the central bank faces a larger sacrifice ratio and optimal policy consists of a slightly looser stance.

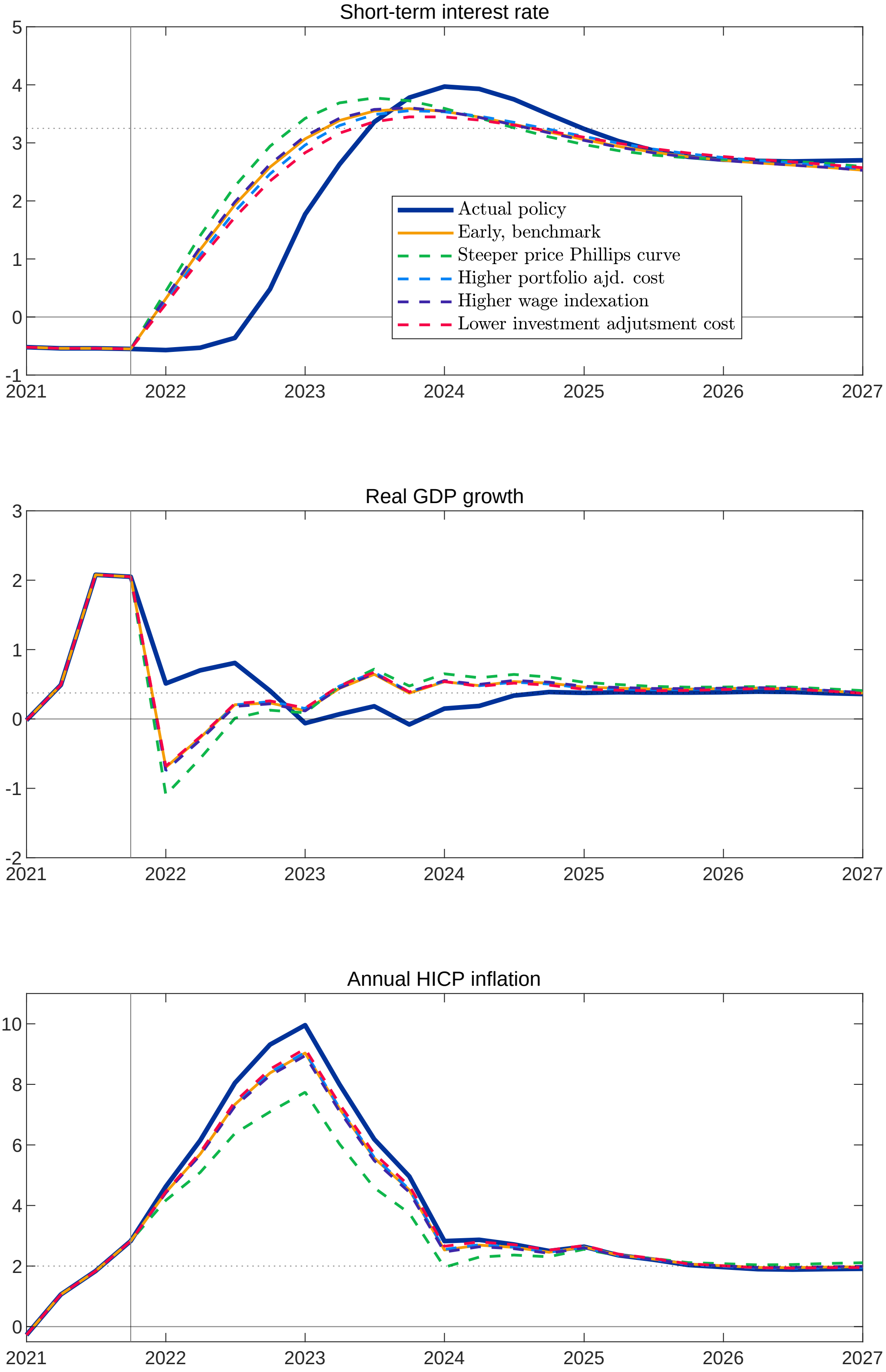
Degree of wage indexation Given the resilience of the labor market during the tightening cycle under investigation and the recent behavior of wages in the euro area (Arce et al., 2024), we next consider sensitivity of optimal counterfactuals to the degree of wage indexation (to inflation) of intermediate-goods producers. Wage indexation plays a key role in shaping the transmission of monetary policy by influencing the degree of nominal rigidity in the labor market and the persistence of inflation.

We provide robustness to this mechanism by increasing the degree of wage indexation to $\chi_W = 0.7$ from the benchmark estimated value of $\chi_W = 0.36$. Since higher indexation slows the adjustment of real wages and adds inertia to inflation dynamics, the required peak rate to lower inflation and improve on the output gap is slightly higher and more persistent relative to the benchmark calibration. However, quantitatively, the higher degree of wage indexation produces negligible differences on inflation and the output gap across model environments, as while real wages now adjust more slowly to past inflation, current inflation also reflects the slower reduction in future real marginal costs.

Strength of investment adjustment costs Among the factors that influence the transmission of a monetary policy, an important role is played by real rigidities. The latter include habit persistence in households' consumption and adjustment costs paid by firms when changing their investment decisions. The purpose of introducing some degree of real rigidities in the model is to reproduce the sluggish response of real variables that is observed in the data following the impact of exogenous shocks. In order to explore the role of real rigidities in the transmission of optimal monetary policy, we lower the strength of investment adjustment costs that intermediate-goods firm face, from $\gamma_I = 9$ to $\gamma_I = 1$ such that real rigidities are lowered to the extent possible.

Reducing the real rigidities parameters is akin to removing the sluggishness in the response of output. As a result, the optimal policy counterfactual results in a lower peak rate to stabilize output and inflation. Notably, despite the lower peak rate, the response of inflation is not significantly different from the baseline parametrization. As output components adjust more rapidly to optimal policy, current inflation also reflects the reduction in future aggregate demand via the Phillips curve.

Figure 6: Optimal policy projections with parametric sensitivity



Note: This figure depicts counterfactual optimal policy projections in 2021:Q4 conditioning on the data and macroeconomic outlook from Eurosystem's staff projections in December 2023 (solid blue lines), in models with alternative parametrization of the slope of the price Phillips curve, the households' portfolio adjustment costs, the degree of wage indexation, or the strength of investment adjustment costs.

4.3 Private-sector expectation formation

Optimal policy is implemented under commitment such that policy announcements about future policy affect the contemporaneous behaviour of agents via anticipated shocks. In models with rational expectations, these anticipated shocks may lead to implausibly strong effects on macroeconomic variables, the so-called "forward guidance puzzle". To attenuate the propagation of interest rate shocks in the NAWM II, we have so far used the method in Gabaix (2020) by assuming that only 80% of private-sector agents in the model are attentive to policy announcements in line with empirical estimates from Coenen et al. (2022). Specifically, in each period, the impulse responses of the endogenous macroeconomic variables to the anticipated policy shocks are attenuated by the share of private sector agents that are assumed to be inattentive.[12]

To further check the robustness of our optimal policy results we next compute optimal policy under alternative expectation formation mechanisms, such as imperfect credibility (Haberis et al., 2019), a finite planning horizon (Woodford, 2018) and learning as in Cole (2021), following closely the approach in de Groot et al. (2021). Specifically, under imperfect credibility, we let the fraction of agents incorporating the policy shock decaying in the horizon h of the announcement according to α^h with $\alpha = 0.8$. Instead, under a finite planning horizon, agents are assumed to completely dismiss policy shocks anticipated to hit beyond a 4-quarter period in the formation of their expectations. Finally, under learning, we assumed that a fraction of agents initially dismiss optimal policy announcements, but this fraction declines over time rendering agents to progressively understand the central bank's commitment with more certainty. In particular, in the learning case, the degree to which anticipated policy shocks are integrated into expectations is defined by a two-parameter logistic function, were $\beta_1 = 1$ defines the speed of learning about the central bank's commitment to its announcement, and $\beta_2 = 5$ defines the initial beliefs.

The results are summarized in Figure 7,[13] and overall suggest that the way in which bounded rationality of the private sector is introduced impacts the aggressiveness of optimal central bank policy both in terms of speed of tightening and the peak rate achieved as well as the persistence of the restrictive stance.[14]

On the one hand, under imperfect credibility, unlike under inattention, the share of agents incorporating the policy shocks into their expectations decays exponentially with the policy horizon. As a result, policy announcements further away in the future are therefore even less effective under imperfect credibility than under inattention, which necessitates a lower peak rate as agents would incrementally observe the policy easing impulse, relative to the baseline. Similarly, under learning much of the tightening is frontloaded as policy shocks are largely unanticipated in the short run, while in subsequent periods the degree of anticipation steadily increases so the optimal policy

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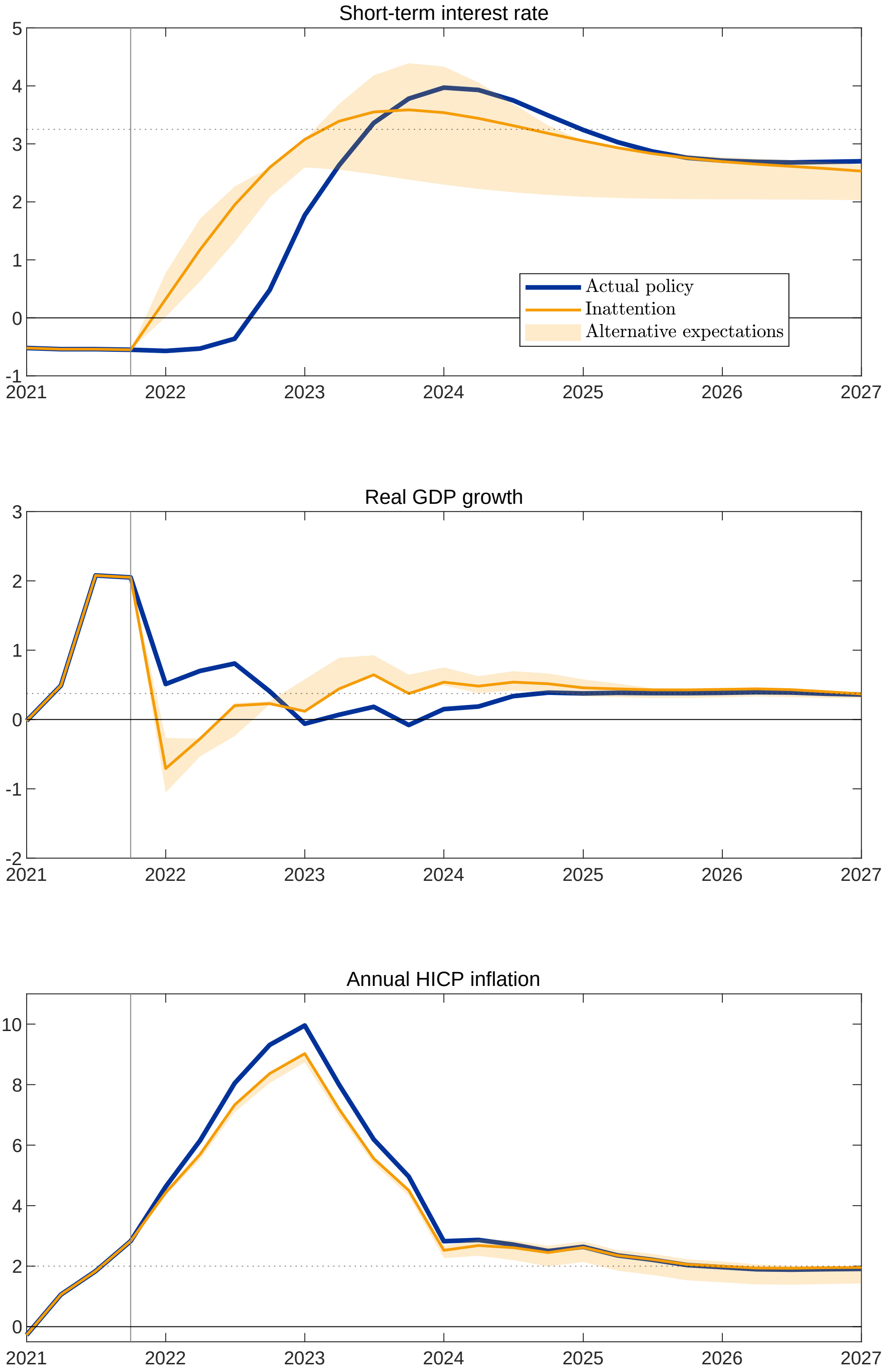
[12] Given that the degree of dampening of the forward guidance puzzle has implications for optimal monetary policy (Nakata et al., 2019) we perform additional simulations (not shown here) with different degrees of rational inattention. Fully removing the share of inattentive agents would produce larger effects but appear implausible due to the forward guidance puzzle. However, our results are broadly robust to varying the degree of attention to policy announcements between the empirically plausible range of 90% and 50%.

[13] Figure A.5 in the Appendix presents the associated optimal policy projections for each type of alternative expectation formation mechanism.

[14] Notably, Carrier and Mavromatis (2024) show that when both the interest rate and central bank asset holdings are set optimally, expectations are found to significantly influence the optimal interest rate trajectory.

Figure 7: Optimal policy projections with alternative expectation formation mechanisms



Note: This figure depicts counterfactual optimal policy projections conditioning on the data and macroeconomic outlook from Eurosystem's staff projections in December 2023 (solid blue lines). Optimal policy paths are computed from 2021:Q4 onward, under commitment, assuming 20% inattention of the private sector to future policy shocks (solid yellow lines). The yellow area includes the range of other private-sector expectation formation mechanisms: imperfect credibility, finite planning horizons and learning.

stabilises at a level somewhat below. These result lends support to Giannoni et al. (2020) which argue that the central bank should be less aggressive following inflationary pressures when the private sector deviates from rationality. However, under finite planning horizons, agents completely ignore policy shocks beyond 4 quarters ahead, implying a more gradual tightening but ultimately higher peak rates. The latter alternative of deviating from rational expectations lends instead support to Gaspar et al. (2010), Gàti (2023), and Hommes et al. (2023), who suggest that an optimal monetary policy is tighter following inflationary pressures in a boundedly rational environment.

5 Conclusion

We have assessed the impact of monetary policy on macroeconomic outcomes by focusing on changes to interest rate policy in the post-pandemic environment. We employed the NAWM II, the workhorse DSGE model for policy analysis at the ECB, and confronted it with alternative, counterfactual monetary policy strategies since mid-2021. Our intention was to contrast the impact from actual ECB policy against alternative strategies that differ in their timing, optimality, and reflection of monetary policymaker preferences.

Our findings indicate that the ECB managed to stabilize inflation and output relatively effectively, albeit with some trade-offs. According to the model-based analysis, the actual policy path—starting rate hikes in 2022:Q3—led to a short-lived economic slowdown, with inflation projected to return to target by end-2025 and interest rates peaking at 4%. An earlier tightening in 2021:Q4 would have lowered peak inflation to 8%, instead of 10%, but triggered a more prolonged recession. Conversely, postponing the hike to 2024:Q1 would have supported short-term growth but allowed inflation to remain elevated—above 4% until 2026. Simulations of optimal policy suggest that a more aggressive stance could have further reduced inflation volatility, though at the cost of a deeper downturn. Real-time counterfactuals show that actual policy closely tracked the optimal path, effectively balancing inflation control with output stabilization. Most alternative strategies, aside from a delayed response, enhanced price stability but exacerbated output volatility—underscoring the ECB's success in navigating the inflation-growth trade-off.

Finally, it is worth acknowledging that the validity of these counterfactual results depends on key model assumptions. The use of a first-order approximation may not fully capture nonlinearities from sizable shocks, while the assumption of anchored longer-term inflation expectations may reduce feedback effects on inflation. We leave these extensions to further research.

References

Adjemian, S., H. Bastani, M. Juillard, F. Karamé, F. Mihoubi, W. Mutschler, J. Pfeifer, M. Ratto, N. Rion, and S. Villemot (2022): "Dynare: Reference Manual Version 5," Dynare Working Papers 72, CEPREMAP.

Adjemian, S., M. Darracq Pariès, and S. Moyen (2007): "Optimal monetary policy in an estimated DSGE for the euro area," Working Paper Series 803, European Central Bank.

Adolfson, M., S. Laséen, J. Lindé, and L. E. Svensson (2011): "Optimal Monetary Policy in an Operational Medium-Sized DSGE Model," *Journal of Money, Credit and Banking*, 43, 1287–1331.

Altavilla, C. and M. Ciccarelli (2011): "Monetary Policy Analysis in Real-Time. Vintage combination from a real-time dataset," CSEF Working Papers 274, Centre for Studies in Economics and Finance (CSEF), University of Naples, Italy.

Arce, , M. Ciccarelli, C. Montes-Galdón, and A. Kornprobst (2024): "What caused the euro area post-pandemic inflation?" Occasional Paper Series 343, European Central Bank.

Barnichon, R. and G. Mesters (2023): "A Sufficient Statistics Approach for Macro Policy," *American Economic Review*, 113, 2809–2845.

Brand, C., M. Obstbaum, G. Coenen, D. Sondermann, R. Lydon, V. Ajevskis, F. Hammermann, S. Angino, N. Hernborg, H. Basso, M. Hertweck, and Bi (2021): "Employment and the conduct of monetary policy in the euro area," Occasional Paper Series 275, European Central Bank.

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

Carlstrom, C. T., T. S. Fuerst, and M. Paustian (2017): "Targeting Long Rates in a Model with Segmented Markets," *American Economic Journal: Macroeconomics*, 9, 205–242.

Carrier, A. and K. Mavromatis (2024): "Optimal normalization policy under behavioral expectations," Working Papers 800/2024, De Nederlandsche Bank.

Cecion, M., G. Coenen, R. Gerke, H. Le Bihan, R. Motto, P. Aguilar, V. Ajevskis, S. Giesen, U. Albertazzi, N. Gilbert, and A. Al-Haschimi (2021): "The ECB's price stability framework: past experience, and current and future challenges," Occasional Paper Series 269, European Central Bank.

Ciccarelli, M., M. Darracq Pariès, and R. Priftis (2024): "ECB macroeconometric models for forecasting and policy analysis: development, current practices and prospective challenges," Occasional Paper Series 344, European Central Bank.

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

Coenen, G., C. Montes-Galdón, A. Saint Guilhem, J. Hutchinson, and R. Motto (2022): “Rate forward guidance in an environment of large central bank balance sheets: a Eurosystem stock-taking assessment,” Occasional Paper Series 290, European Central Bank.

Cole, S. J. (2021): “Learning and the Effectiveness of Central Bank Forward Guidance,” *Journal of Money, Credit and Banking*, 53, 157–200.

Crump, R., M. Del Negro, K. Dogra, P. Gundam, D. Lee, R. Nallamotu, and B. Pacula (2023): “The New York Fed DSGE Model Perspective on the Lagged Effect of Monetary Policy,” Federal Reserve Bank of New York Liberty Street Economics.

Darracq Pariès, M. and M. Kühl (2016): “The optimal conduct of central bank asset purchases,” Working Paper Series 1973, European Central Bank.

De Fiore, F., B. Mojon, D. Rees, and D. Sandri (2023): “Monetary policy frameworks away from the ELB,” BIS Working Papers No 1156.

de Groot, O., F. Mazelis, R. Motto, and A. Ristiniemi (2021): “A Toolkit for Computing Constrained Optimal Policy Projections (COPPs),” European Central Bank, Working Paper Series No. 2555.

De Santis, R. A. and T. Tornese (2023): “Energy supply shocks’ nonlinearities on output and prices,” Working Paper Series 2834, European Central Bank.

Debortoli, D., J. Kim, J. Lindé, and R. Nunes (2019): “Designing a Simple Loss Function for Central Banks: Does a Dual Mandate Make Sense?” *The Economic Journal*, 129, 2010–2038.

Dengler, T., R. Gerke, S. Giesen, D. Kienzler, J. Röttger, A. Scheer, and J. Wacks (2024): “A primer on optimal policy projections,” Tech. rep.

ECB (2016): “A guide to the Eurosystem/ECB staff macroeconomic projection exercises,” European Central Bank, July 2016.

Gabaix, X. (2020): “A Behavioral New Keynesian Model,” *American Economic Review*, 110, 2271–2327.

Gaspar, V., F. Smets, and D. Vestin (2010): “Inflation Expectations, Adaptive Learning and Optimal Monetary Policy,” in *Handbook of Monetary Economics*, ed. by B. M. Friedman and M. Woodford, Elsevier, vol. 3 of *Handbook of Monetary Economics*, chap. 19, 1055–1095.

Gàti, L. (2023): “Monetary policy & anchored expectations—An endogenous gain learning model,” *Journal of Monetary Economics*, 140, 37–47.

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

——— (2013): "QE 1 vs. 2 vs. 3. . . : A Framework for Analyzing Large-Scale Asset Purchases as a Monetary Policy Tool," *International Journal of Central Banking*, 9, 5–53.

Giannoni, M., B. Preston, and S. Eusepi (2020): "On the Limits of Monetary Policy," Tech. rep.

Giannoni, M. P. and M. Woodford (2003): "Optimal Interest-Rate Rules: I. General Theory," NBER Working Papers 9419, National Bureau of Economic Research, Inc.

Haberis, A., R. Harrison, and M. Waldron (2019): "Uncertain policy promises," *European Economic Review*, 111, 459–474.

Harrison, R. and M. Waldron (2021): "Optimal policy with occasionally binding constraints: piecewise linear solution methods," Bank of England working papers 911, Bank of England.

Hommes, C., K. Mavromatis, T. Özden, and M. Zhu (2023): "Behavioral learning equilibria in New Keynesian models," *Quantitative Economics*, 14, 1401–1445.

Karadi, P., A. Nakov, G. N. Barrau, E. Pasten, and D. Thaler (2024): "Strike while the iron is hot: optimal monetary policy with a nonlinear Phillips curve," BIS Working Papers 1203, Bank for International Settlements.

Lane, P. R. (2023): "The euro area hiking cycle: an interim assessment," Dow Lecture.

Mazelis, F., R. Motto, and A. Ristiniemi (2023): "Monetary policy strategies for the euro area: optimal rules in the presence of the ELB," Working Paper Series 2797, European Central Bank.

McKay, A. and C. K. Wolf (2023): "What Can Time-Series Regressions Tell Us About Policy Counterfactuals?" *Econometrica*, 91, 1695–1725.

Molodtsova, T., A. Nikolsko-Rzhevskyy, and D. H. Papell (2008): "Taylor rules with real-time data: A tale of two countries and one exchange rate," *Journal of Monetary Economics*, 55, 63–79.

Nakata, T., R. Ogaki, S. Schmidt, and P. Yoo (2019): "Attenuating the forward guidance puzzle: Implications for optimal monetary policy," *Journal of Economic Dynamics and Control*, 105, 90–106.

Orphanides, A. (2001): "Monetary Policy Rules Based on Real-Time Data," *American Economic Review*, 91, 964–985.

Schmitt-Grohe, S. and M. Uribe (2007): "Optimal simple and implementable monetary and fiscal rules," *Journal of Monetary Economics*, 54, 1702–1725.

Svensson, L. E. and R. J. Tetlow (2005): "Optimal Policy Projections," *International Journal of Central Banking*, 1.

Svensson, L. E. O. (2005): "Monetary Policy with Judgment: Forecast Targeting," *International Journal of Central Banking*, 1.

Svensson, L. E. O. and M. Woodford (2003): "Implementing Optimal Policy through Inflation-Forecast Targeting," NBER Working Papers 9747, National Bureau of Economic Research, Inc.

Tetlow, R. J. (2022): "How Large is the Output Cost of Disinflation?" Finance and Economics Discussion Series 2022-079. Washington: Board of Governors of the Federal Reserve System.

Woodford, M. (2001): "Fiscal Requirements for Price Stability," *Journal of Money, Credit and Banking*, 33, 669–728.

——— (2010): "Robustly Optimal Monetary Policy with Near-Rational Expectations," *American Economic Review*, 100, 274–303.

——— (2018): "Monetary Policy Analysis When Planning Horizons Are Finite," in *NBER Macroeconomics Annual 2018, volume 33*, National Bureau of Economic Research, Inc, NBER Chapters, 1–50.

A Appendix

A.1 AIT vs. optimal policy

Given the hump-shaped nature of our optimal interest rate paths, we explore whether an AIT framework can produce similar effects, as was the implemented policy in the United States during the post-pandemic tightening cycle.

Specifically, we run rule-based policy projections where the central bank sets interest rates according to an average inflation targeting (AIT) rule, by targeting the moving average of the inflation gap. We assess how the standard inflation targeting rule compares to the 1-year AIT rule, which is commensurate with targeting year-on-year inflation, as well as 2-year AIT, 3-year AIT and 4-year AIT. The experiment differs from the optimal policy projections to the extent that AIT rule is backward looking, as the central bank sets the policy rate according to a systematic response to observed shortfalls of inflation from the target over several quarters, while optimal policy is forward looking and instead consists of minimizing the projected welfare loss.

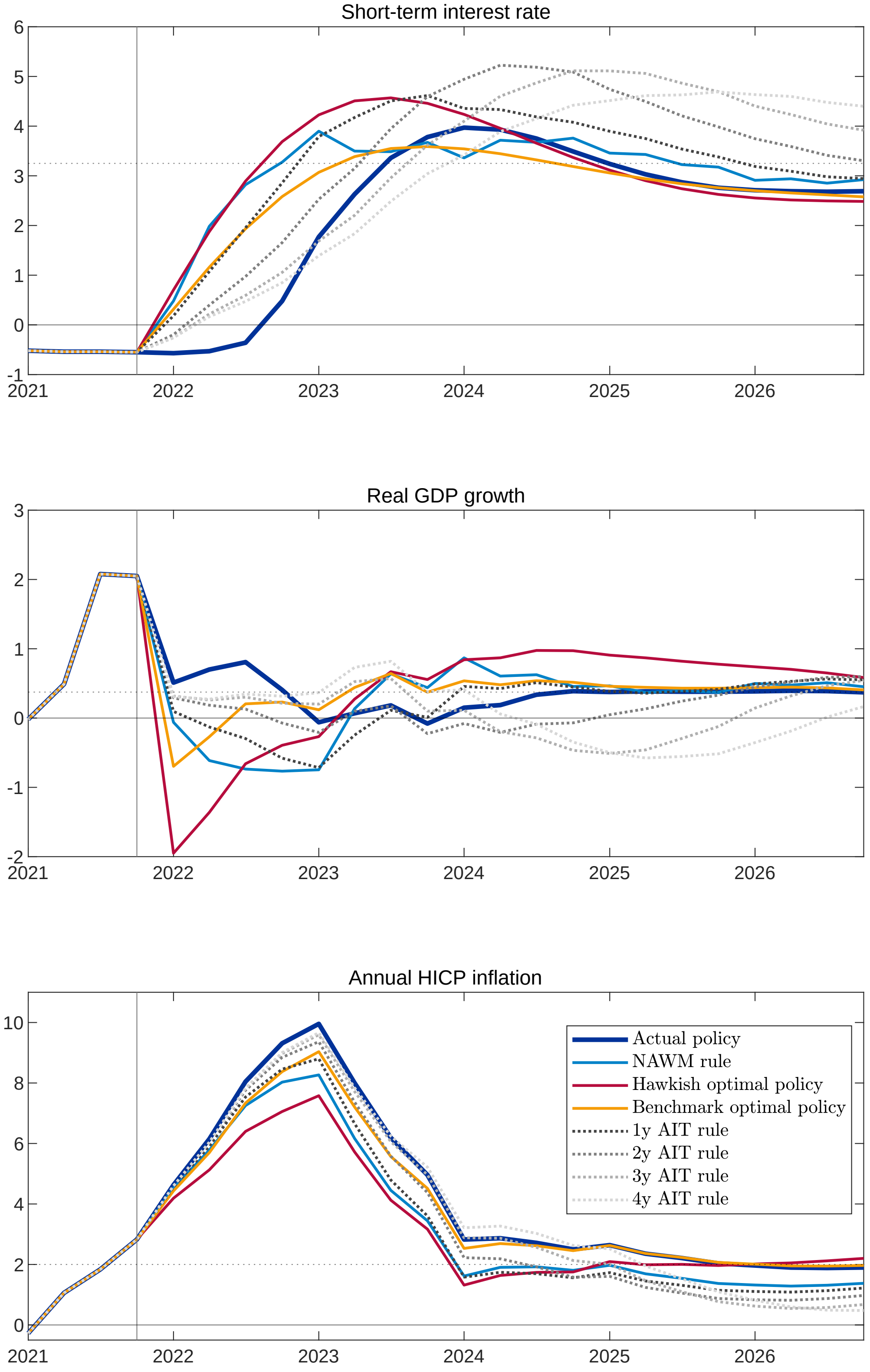
The AIT specification over q quarters requires the interest rate rule to now take the following form:

$$i_t \;=\; \rho\, i_{t-1} + (1-\rho)\left(\bar{r} + \bar{\pi} + \phi_{\hat{\pi}}\,\frac{1}{q}\sum_{j=0}^{q-1}\hat{\pi}_{t-q} + \phi_{\Delta\pi}\,\Delta\pi_t + \phi_{\hat{y}}\,\hat{y}_t + \phi_{\Delta\hat{y}}\,\Delta\hat{y}_t\right) + \eta_t \tag{8}$$

where the inflation gap is now replaced by the average inflation gap over the last q quarters.

Conditioning on the December 2023 baseline, our results suggest that—in hindsight—an AIT rule would prescribe an earlier lift off from the effective lower bound already in 2021:Q4. The results are similar to the evidence in Crump et al. (2023) which provide a model-based prediction using the FRB/US model by allowing the US Federal Reserve to follow an AIT rule, but also line with the optimal policy and (estimated) rule-based prescriptions from our analysis. However, the speed of hiking is more gradual under the AIT rule relative to optimal policy because AIT takes into account accumulated inflation shortfalls before the inflation surge while optimal policy is conditional on inflation forecasts. Given that the average inflation rate was below 2% before 2021, when inflation started to rise above the target in the second half of 2021, a central bank stabilising a moving average of the inflation rate tolerates above-target inflation until the average inflation gap closes. As a result, under an AIT rule, the central bank hikes the policy rate once the inflation gap turns positive and maintains it persistently higher until inflation undershoots the target to allow the average inflation gap to close in the medium term. In particular, the gradualism of rate hiking, i.e., the number of quarters required to reach the peak rate, increases with the duration of the AIT window.

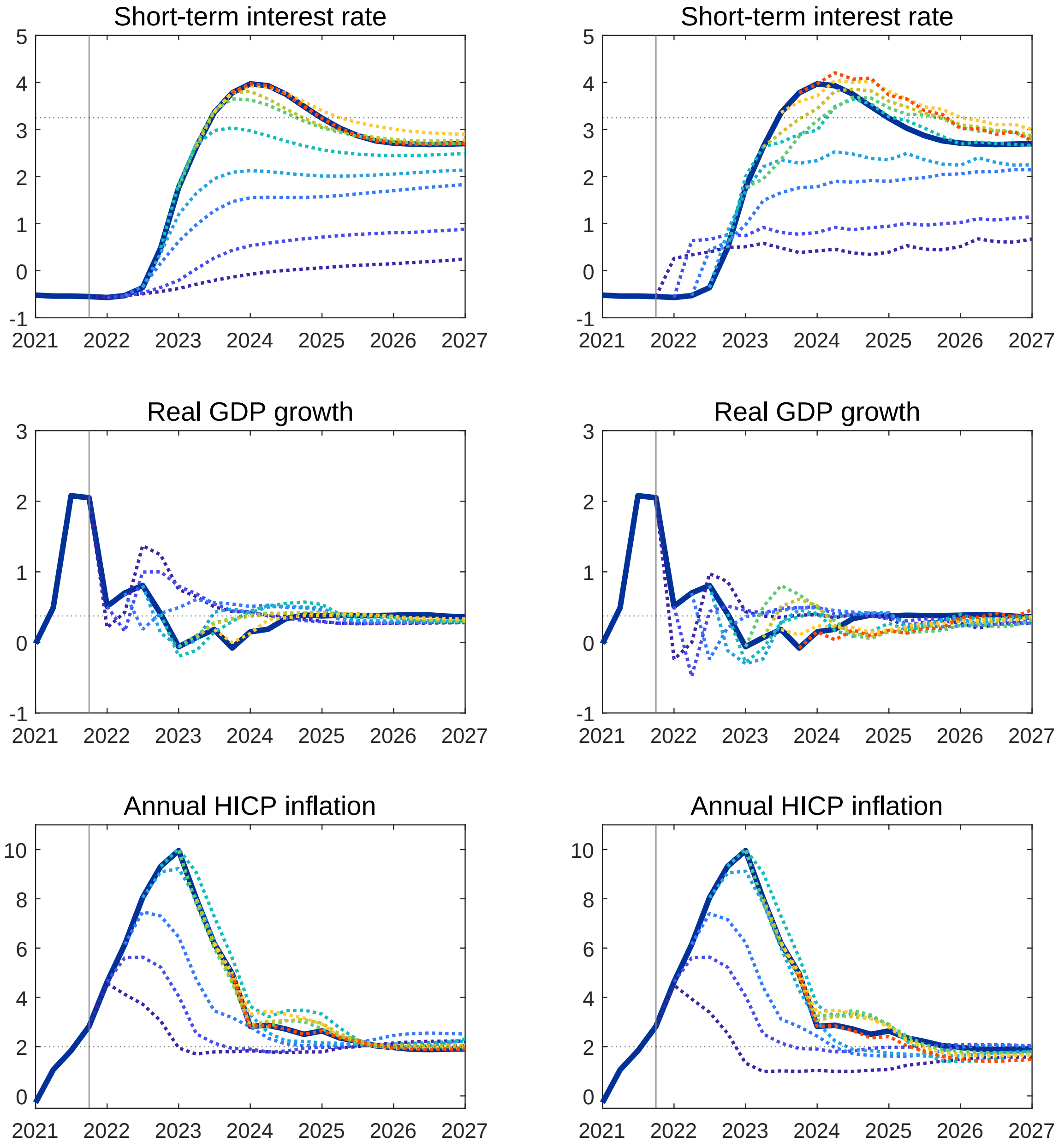
Figure A.1: AIT rule-based counterfactuals in 2021:Q4



Note: This figure depicts counterfactual AIT rule-based policies in 2021:Q4 conditioning on the data and macroeconomic outlook from Eurosystem's staff projections in December 2023 (solid blue lines). Under AIT rules, the central bank targets average inflation over a period between 1 year and 4 years.

A.2 Real-time counterfactuals

Figure A.2: Real-time forecasts between December 2021 and December 2023

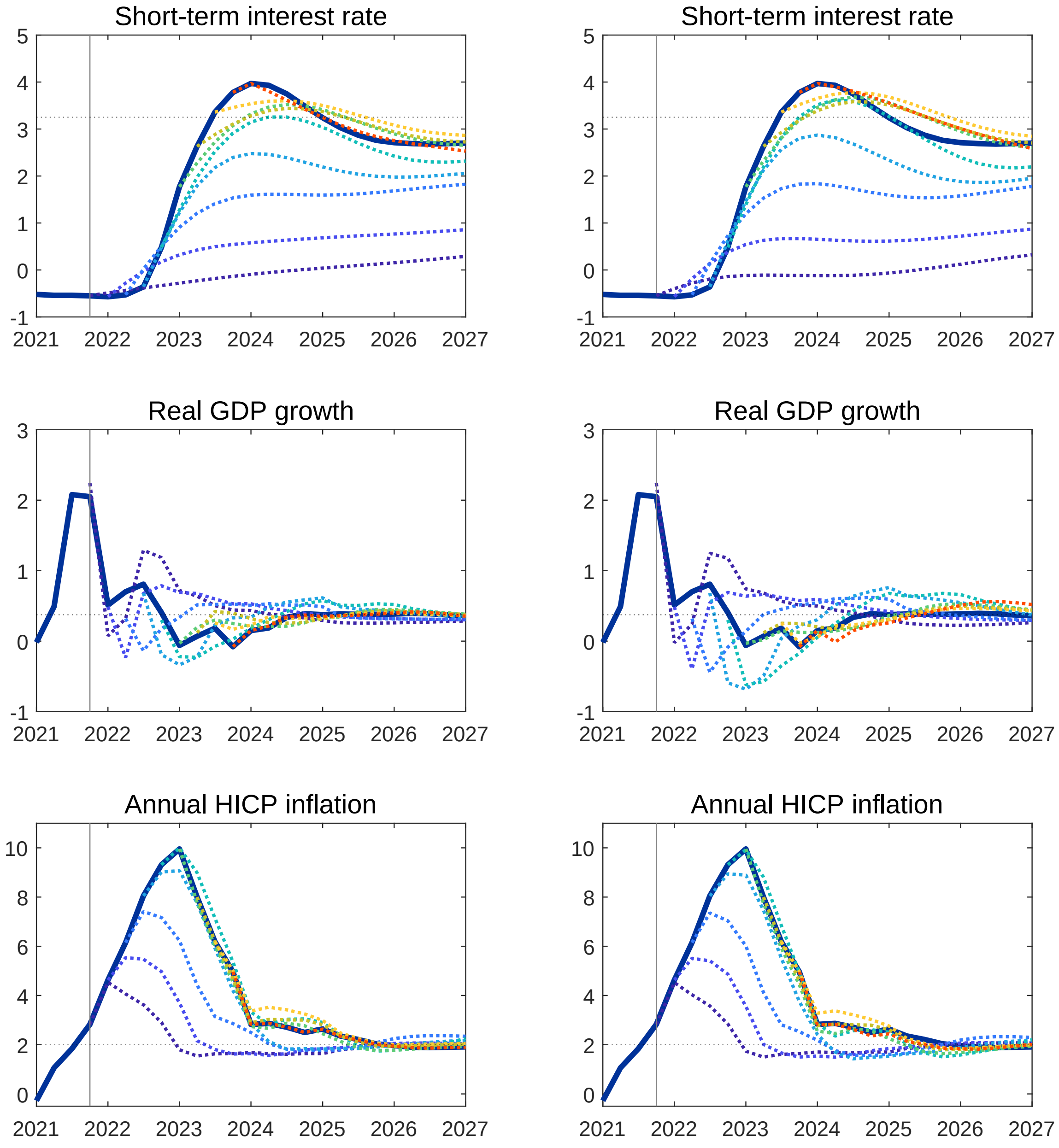


A. Baseline projections

B. Rule-based policy

Note: This figure depicts counterfactual rule-based policy (right) conditioning on quarterly real-time ECB / Eurosystem's staff projections (left) between 2021:Q4 and 2023:Q4. The policy projections are computed and updated each quarter by finding the policy path consistent with the feedback rule of the model.

Figure A.3: Real-time forecasts between December 2021 and December 2023



C. Optimal policy $\lambda_y = 0.5$

D. Optimal policy $\lambda_y = 0.1$

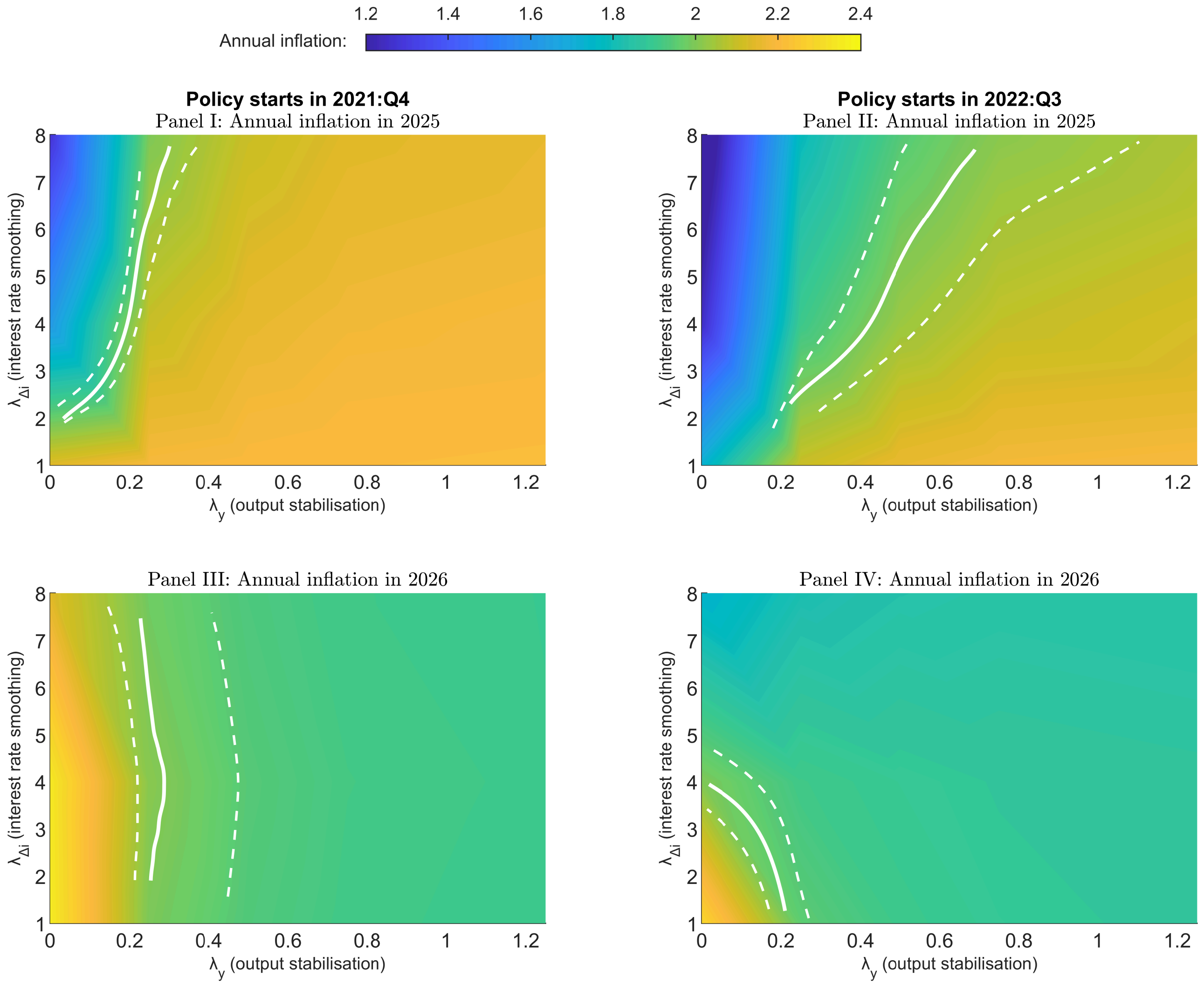
Note: This figure depicts counterfactual optimal policy projections under alternative parameterizations of the central bank loss function conditioning on quarterly real-time ECB / Eurosystem's staff projections (left) between 2021:Q4 and 2023:Q4.

A.3 Policy preferences

Figure A.4 depicts projected annual HICP inflation in 2025 (top row, Panels I and II) and 2026 (bottom row, Panels III and IV) under counterfactual optimal policy simulations that start in 2021:Q4 (left) or 2022:Q3 (right) conditional on the December 2023 macroeconomic projection baseline. Each point on each grid represents a certain parameter combination of λ_y and $\lambda_{\Delta i}$.

If policymakers aim to achieve price stability in 2025 (Panels I and II), λ_y and $\lambda_{\Delta i}$ are positively associated. For the combination of shocks affecting the economy over that period, a more gradual steering of the interest rate due to output considerations must be offset by greater persistence of rate path. When optimal policy is initiated in 2022:Q3, the policy horizon shrinks by three quarters. Lags inherent to monetary policy transmission entail a more moderate tightening impulse overall to stabilize inflation at the target in 2025: all else equal, a higher weight on output is compatible with price stability, i.e, the isocurve shifts to the right. A later start therefore implies reduced macro-financial volatility compared to an earlier start. If policymakers instead aim to achieve price stability in 2026 (Panel III and IV), λ_y and $\lambda_{\Delta i}$ are weakly associated. Target-consistent preferences for a policy initiated in 2021:Q4 require a weight on output between 0.2 and 0.3 for any given weight on interest rate smoothing. Instead, λ_y and $\lambda_{\Delta i}$ would be negatively associated when policy is initiated later, implying that higher output considerations must be compensated for with lower smoothing and vice versa.

Figure A.4: Policy preferences consistent with medium-term price stability



Policy starts in 2021:Q4

Panel I: Annual inflation in 2025

Policy starts in 2022:Q3

Panel II: Annual inflation in 2025

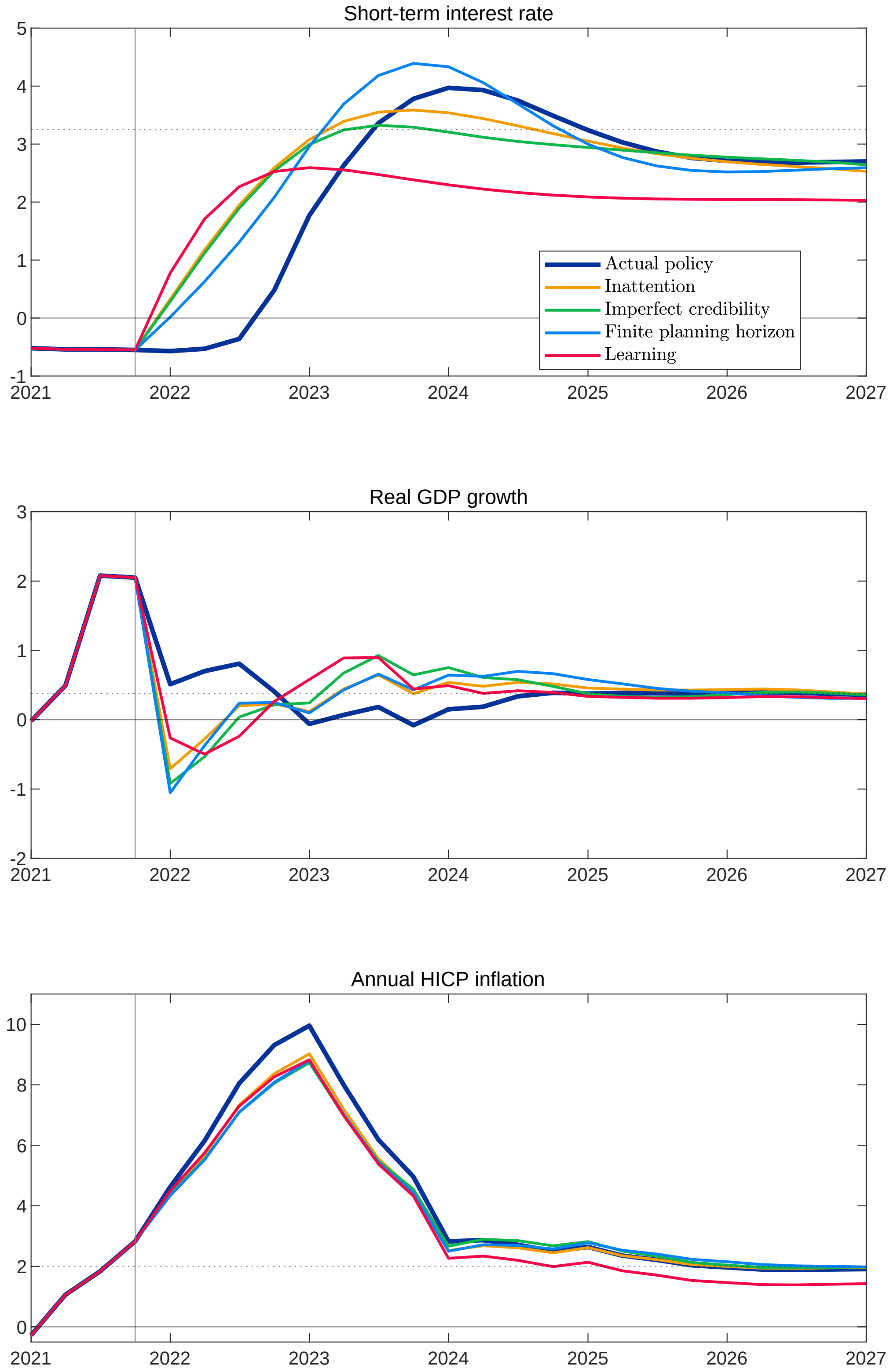
Panel III: Annual inflation in 2026

Panel IV: Annual inflation in 2026

Note: This figure depicts projected annual HICP inflation in 2025 (top row) and 2026 (bottom row) under optimal policy counterfactual simulations that start in 2021:Q4 (left) or 2022:Q3 (right) conditioning on the data and macroeconomic outlook from Eurosystem's staff projections in December 2023. Each panel is constructed using alternative combinations of parameter values for λ_y and $\lambda_{\Delta i}$, the weights of output and interest rate smoothing relative to price stability in the loss function. The pairs of parameters delivering 2% inflation in 2025 and 2026 are interpolated linearly.

A.4 Sensitivity to expectations

Figure A.5: Optimal policy projections with alternative expectation formation mechanisms



Note: This figure depicts counterfactual optimal policy projections conditioning on the data and macroeconomic outlook from Eurosystem's staff projections in December 2023 (solid blue lines). Optimal policy paths are computed from 2021:Q4 onward, under commitment, assuming inattention of the private sector to future policy shocks (yellow), imperfect credibility (green), 4-quarter finite planning horizons (blue) and learning (red).

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