EUROPEAN CENTRAL BANK

EUROSYSTEM

Working Paper Series

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

No 2935

Abstract

We evaluate how the euro area economy would have performed since mid-2021 under alternative monetary policy strategies. We use the ECB's workhorse estimated DSGE model and contrast actual policy conduct against alternative strategies which differ in their "lower-for-longer" commitment as well as policymaker preferences regarding inflation and output volatility. Assuming that the monetary authority had full knowledge of prevailing conditions from mid-2021 onwards, the alternative policy strategies would call for anticipated timing of the start of the hiking cycle: earlier tightening would prevent inflation from peaking at 10%, but the forceful tightening since 2022:Q3 prevented higher inflation from becoming entrenched. However, once evaluating monetary policy on real-time quarterly vintages of incoming data and projections, the alternative interest rate paths would be broadly consistent with the observed policy conduct. The proximity of some benchmark optimal policy counterfactuals with the baseline, brings further indication that the actual policy conduct succeeded in implementing an efficient management of the output-inflation trade-off.

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

Due to the Covid-19 pandemic, unexpected and prolonged shocks hit the euro area economy, necessitating fiscal and monetary authorities to counteract their macroeconomic effects through expansionary measures. Coupled with pent-up demand following the easing of restrictions, and subsequently, a renewed reduction in the supply of imported energy within the euro area, this paved the path for a notable surge in inflation. In response to increasing inflation in 2021, the 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 at 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, and is expected to converge to the 2% medium-term target in 2025 according to the December 2023 projection baseline.

This paper attempts to 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. Our intention is to contrast the impact of actual policy against alternative strategies that differ in their timing, optimality, and reflection of monetary policymaker preferences, using a state-of-the-art DSGE policy model tailored to provide quantitative prescriptions regarding euro area monetary policy.

We first introduce the estimated structural model and provide a structural narrative about the sources of macroeconomic fluctuations since 2020 by disentangling the contributions to real GDP growth and annual HICP inflation of the various shocks affecting the euro area economy. Negative supply shocks reflecting the weak post-pandemic supply capacity, high markups and distorted global value chains hit the economy at the end of 2021, weakening the resilience of demand, which was supported by expansionary monetary and fiscal policies. Supply bottlenecks were further exacerbated by the war between Russia and Ukraine starting in 2022:Q1, which caused euro area energy and food prices to soar and led inflation to significantly and persistently overshoot the 2% target. With regards to monetary policy, the model identifies increasingly negative interest rates shocks between 2021:Q1 and 2022:Q2, with positive contributions to price inflation of up to 2 percentage points in 2022, suggesting that in hindsight, monetary policy responded to inflationary pressures with some delay, supporting however real economic activity.

Using as benchmark the official macroeconomic projections by the ECB and the Eurosystem, we then employ the NAWM II to simulate the effects on GDP growth and inflation under a strategy where interest rate policy follows the estimated Taylor-type rule of the model, at different points in time. This counterfactual enables answering the question of whether the timing of the interest rate hiking cycle matters. In particular, what would have happened to interest rates, output, and inflation had the ECB followed the estimated interest rate rule of the model since 2021:Q4—when inflation rose to 4.7% and began to significantly overshoot the target—as opposed to maintaining the lower-for-longer policy until 2022:Q2 and raising interest rates aggressively thereafter. Specifically, the rule-based projection is implemented by performing a conditional forecast, conditioning on all macroeconomic shocks other than the standard monetary policy shock.

The results suggest that, assuming full information about the macroeconomic conditions that would prevail since 2021, the timing of the start of the hiking cycle matters for euro area macroeconomic dynamics. In hindsight, an earlier hike would have minimised the peak of inflation and achieved convergence to the target faster. Yet, the counterfactual exercise that begins in 2022:Q3 delivers broadly similar outcomes to the actual policy conduct. The experiment therefore suggests that the interest rate rule of the NAWM II tracks relatively well observed policy from 2022:Q3 to 2024:Q1.

While the conditional forecast with the model-consistent interest rate rule allows gauging the effects of alternative starting dates of the hiking cycle, a second natural question that arises is, what would have been the effects on the euro area economy if monetary policy was designed optimally. We answer this question by computing the optimal interest rate path at different points in time, which is endogenously determined by means of minimizing an intertemporal loss function consistent with the central bank price stability orientation over the medium term. Methodologically, our approach follows a constrained optimal policy projection as in de Groot et al. (2021). Harrison and Waldron (2021) and Carrier and Mavromatis (2024) have employed similar frameworks in related studies. We show that, compared to the rule-based projections, optimal policy projections are more hump-shaped, with higher peak rates but less persistence of the restrictive stance. The benchmark preferences, once assuming the 2022:Q3 lift-off date, would engineer a mild recession and deliver inflation outcomes quite similar to the baseline. Conversely, more hawkish preferences would imply a deeper recession and inflation undershooting the target by 2024 already. The proximity of the benchmark optimal policy macroeconomic allocation with the baseline, brings further indication that the actual policy conduct managed to implement an efficient management of the output-inflation trade-off.

The medium-term orientation of monetary policy means that it is forward-looking and depends on the economic outlook: macroeconomic projections must therefore be accurate to adequately calibrate policy. In practice, unexpected macroeconomic shocks lead to forecast errors, and render policy suboptimal ex-post. For instance, the Russian invasion of Ukraine in 2022:Q1 and the war since then caused persistent supply disruptions and an increase in energy prices. Had the ECB forecast this event and its economic effects in December 2021, this would have justified hiking interest rates earlier.

We simulate policy counterfactuals in real-time to assess the respective role of ”bad luck” (i.e. one-sided repeated adverse shocks hitting the euro area economy) and ”bad policy” (i.e. delayed adjustment of monetary policy stance and the management of the ouptut-inflation trade-off compared with alternative monetary policy conduct) 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. Our results suggest that, unlike in simulations with perfect foresight about the sequence of shocks hitting the economy between 2021:Q4 and 2023:Q4, 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 the full-information counterfactuals. 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 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.

As the validity of our findings rely on the validity of the model itself, there is considerable uncertainty around several aspects of our analysis. We discipline the uncertainty around key dimensions by undertaking robustness checks on: the specification of policymaker preferences in the central bank’s loss function and the strength of the transmission of policy (through the slope of the Phillips curve and the degree of financial frictions). We also highlight the importance of agent expectations in shaping the predictions of optimal policy and simulate optimal policy counterfactuals under imperfect credibility, a finite planning horizon and learning. We find that policy announcements further away in the future are less effective under imperfect credibility and learning, whereas a more gradual tightening is optimal under a finite planning horizon.

Related literature Our paper is related to three branches of the literature on monetary policy using model-based studies.

First, there exist a number of works evaluating counterfactual monetary policy strategies during the post-pandemic inflation period using medium- or larger-scale policy models. Similar to us, Crump et al. (2023) use the New York Fed's DSGE model to build counterfactual simulations in which the Federal Reserve deviates from a lower-for-longer effective lower bound policy and instead follows an average inflation targeting rule in 2021. Under such a strategy, the Federal Reserve would have hiked the federal funds rate from 0.25% in 2021:Q2 to around 4.5% at the end of 2023, an interest rate path which is similar to the one we obtain for the euro area. De Fiore et al. (2023) analyse the role of alternative monetary policy rules in the US after the pandemic. They compare actual policy against an aggressive inflation targeting framework, or an interest rate peg until 2025:Q2 followed by a return to a standard inflation targeting strategy. Similar to our predictions, they find that none of these rules, even when coefficients are optimised to minimise welfare losses, would have prevented inflation from surging initially.

Second, our work is related to the optimal monetary policy literature, in particular studies employing larger-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), among others, and in particular Harrison and Waldron (2021) who employ a similarly-sized policy model (FRB/US model) for such an evaluation using off-model information to inform their baseline. Additionally, our work also speaks to recent studies evaluating the welfare of unconventional monetary policy normalization from a model-consistent perpesctive, such as Karadi and Nakov (2021); Benigno and Benigno (2022); Kabaca et al. (2023), Cantore and Meichtry (2023); among others.

Third, we relate to recent normative studies of interest rate policy normalization during the post-pandemic inflation regime under alternative expectations. Using a similar methodology, Carrier and Mavromatis (2024) examine optimal normalization strategies under persistent inflationary shocks when agents' expectations deviate from rational expectations. They identify the interest rate as being they key instrument for managing inflationary pressures, and that greater monetary policy tightening is required when more agents hold de-anchored expectations. In turn, Hakamada and Walsh (2024) evaluate the costs and benefits of delaying the response of monetary policy to a surge in inflation using a calibrated New-Keynesian model under cognitive discounting. While credibly committing to respond to inflation in the future is substitutable to immediate action, they find that delaying the hike is less costly under cognitive discounting instead of rational expectations.

The remainder of this paper is structured as follows. Section 2 introduces the ECB's estimated DSGE model and provides a structural narrative about the sources of macroeconomic fluctuations since 2020. Section 3 simulates counterfactual monetary policy strategies to assess how the euro area economy would have performed had the ECB deviated from actual interest rate policies. Section 4 performs robustness checks, while section 5 concludes. Appendix 5 provides additional figures and information.

2 Model and Data

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 (Broad) Macroeconomic Projection Exercises (BMPE) and for analysis of topical policy issues.[1] It comprises the euro area and a rest-of-the-world block. The model is estimated using Bayesian techniques and the list of observable variables 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 and grouped according to (standard) categories (see the footnote in Figure 1).

In what follows we provide an overview of its main features and how it utilizes a projection baseline as input for monetary policy analysis.[2].

2.1 A bird's eye view of the ECB's NAWM II

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 make optimal choices regarding their purchases of consumption and investment goods, the latter determining the economy-wide capital stock. They supply differentiated labour services in monopolistically competitive markets, and set wages as a mark-up over the marginal rate of substitution between consumption and leisure. Households face a financing constraint for

[1]See e.g., Cecion et al. (2021), and Brand et al. (2021) (and references therein) for recent applications of the ECB's NAWM II model related to price stability, the inflation-output trade off, among others key topical issues.

[2]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)

investments in physical capital, which gives rise to a demand for long-term loans, and they can invest in domestic long-term government bonds subject to portfolio adjustment frictions. 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.

Banks' assets comprise long-term loans to the private sector for investment purposes, domestic and foreign 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. 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 leverage constraint (see, Gertler and Karadi (2011); Gertler and Karadi (2013)). 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.

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.

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-consistent 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, as well as their changes:

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

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.

Table 1: Bayesian estimation of Taylor rule 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

2.2 Macroeconomic projection baseline

The counterfactual monetary policy experiments of section 3 build on a macroeconomic projection baseline for the euro area. 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 each projection round, this baseline is used as an input into the NAWM II, for the purpose of rationalizing and projecting macroeconomic aggregates over the projection horizon.

As a result, the development of the model has been guided by the need to account for a comprehensive set of core projection variables, including a small number of foreign variables, which enter the model in the form of exogenous assumptions. In line with this consideration, 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.

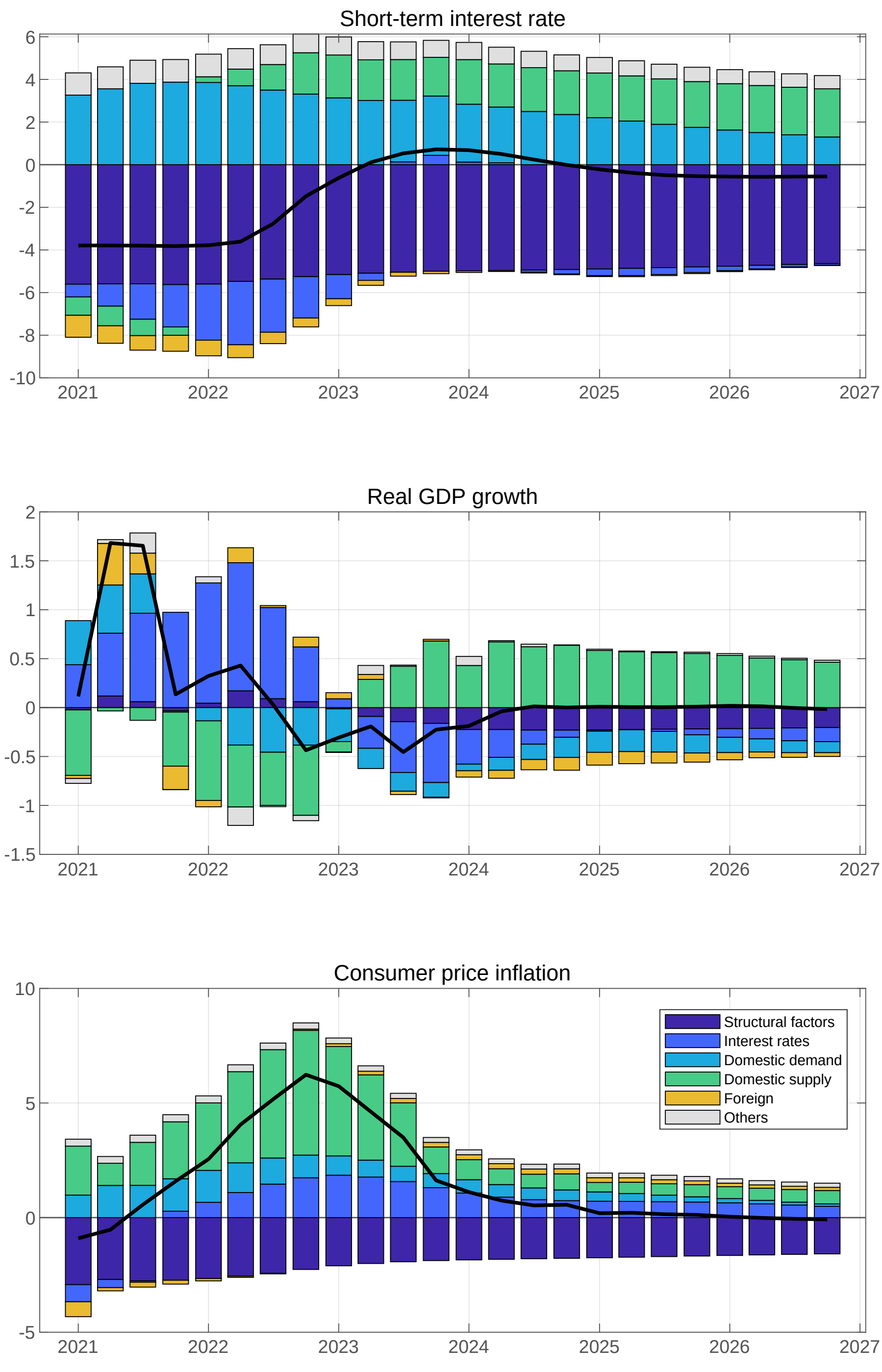
In each projection round, a projection baseline is constructed using exogenous assumptions of the international economic environment, as well as an aggregation of national-level fiscal policies. Interest rates are assumed to follow the euro short-term rate (€STR) forward curve, making the baseline consistent with market-expectations of monetary policy conduct. These assumptions are combined together with additional off-model information, including expert judgement about the transmission and persistence of shocks, and ultimately rationalised by the model to project macroeconomic aggregates in the medium-term. More detailed illustrations of the use of NAWM II for forecasting and policy analysis can be found in Ciccarelli et al. (2024).

2.3 Investigating the drivers of post-pandemic inflation

We validate the model by providing a structural interpretation of macroeconomic data from 2021 onwards. We place ourselves in 2023:Q4 and identify the sequence of structural shocks that best explains observed data from 2021 until 2023:Q3 and the ECB projection baseline from 2023:Q4 to 2026:Q4. This is achieved by filtering state variables and shocks using the state-space representation of the model and the December 2023 BMPE baseline (ECB (2023)). Figure 1 shows the structural decomposition for the short-term interest rate (top panel), real GDP growth (medium panel) and consumer price inflation (bottom panel).

In 2021, the model identifies positive demand shocks and standard monetary policy shocks as the primary drivers of economic growth following the extraordinary reduction in GDP growth as a consequence of the economic lockdowns in response to the COVID-19 pandemic: pent-up demand, accumulated savings and lower-for-longer monetary policy supported the economic recovery. At the end of 2021, demand factors no longer supported growth and several supply shocks hit the economy. Indeed, the resilience of demand until then, supported by expansionary monetary and fiscal policies, contrasted with the weak supply capacity, as intermediate goods suppliers, particularly in China, were still affected by the pandemic. Commodity price inflation, for instance, was already elevated in mid-2021 due to an imbalance between aggregate supply and aggregate demand, as firms competed to purchase critical materials and intermediate goods, resulting in shortages and high markups, hampering the production of a wide range of final consumer goods. Global value chains were also affected as in the short-term firms in the transportation sector were unable to meet the rebound in aggregate demand and instead charged higher transportation fees. In 2022:Q1 these supply bottlenecks were further exacerbated by the war between Russia and Ukraine. Euro area energy and food prices soared due the significant reduction of imports of Russian oil and gas as well as geopolitical uncertainty. In 2022, cost-push shocks propagated to consumer prices, with HICP inflation peaking at 10% and the consumer deflator at 8% in 2022:Q4, as firms passed through higher marginal costs to consumers, in turn dampening

Figure 1: Structural shocks decomposition of euro area rates, GDP growth and inflation



Note: The figure depicts the structural shocks decomposition of the December 2023 baseline for short-term interest rate, quarter-on-quarter real GDP growth and annual HICP inflation, in deviation from their steady state (3.25%, 0.375%, and 2% respectively). "Structural factors" includes the contributions of the initial state, the discount rate shock and the persistent component of the permanent technology shock. "Interest rate shocks" comprises the short-term interest rate shock and the shock to the retail bank's markdown. "Domestic demand" includes the domestic risk-premium shocks and shocks to government spending. "Domestic supply" captures supply-shocks: the transitory component of the permanent technology shock, the transitory and investment specific technology shocks, wage and price mark-up shocks. "Foreign and trade" captures shocks to foreign demand, foreign prices, US 3-month and 10-year interest rates, competitor's export prices, oil prices, import demand, export preferences, mark-up shocks to export and import prices and a foreign risk-premium shock. "Other" includes the contribution of measurement errors and residuals from bridge equations.

aggregate demand.

With regards to monetary policy, it initially looked-through the cost-push shocks of 2021 as both inflation expectations and the ECB projections expected inflation to remain below the target in the medium-term. At the time, this did not warrant a tightening of policy because medium-term price pressures remained subdued (Lane (2024)). Notably, cost push shocks affect the price level permanently but have transitory effects on inflation if long-term inflation expectations are well-anchored. However, the sequence of negative supply shocks and persistent overshooting of the 2% target implied increasingly elevated risks that inflation became entrenched in agents' expectations. Overall, the model identifies negative interest rates shocks between 2021:Q1 and 2022:Q2, with positive contributions to price inflation of up to 2 percentage points in 2022. This suggests that in hindsight, monetary policy responded to inflationary pressures with some delay with the benefit of supporting economic activity.

From 2024 onwards, the shock decomposition suggests that consumer price inflation will moderate and converge to the 2% target as supply shocks unwind, while GDP growth will rebound to some extent despite the negative monetary policy shocks persisting over the forecast horizon.

3 Counterfactual Monetary Policy Strategies

The third quarter of 2022 marked the end of an extended period where the deposit facility rate of the ECB stood at historically low levels since the outbreak of the sovereign debt crisis in 2012. In response to increasing inflation in 2021, the ECB took key actions to unwind its accommodative monetary policy stance. In terms of its primary instruments, the nominal short-term interest rate was raised from -0.5% in 2022:Q3 and reached 4.0% four quarters later in 2023:Q3.[3] 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, and is expected to converge to the 2% medium-term target in 2025 according to the December 2023 projection baseline.

In the next subsections, we assess how the euro area economy would have performed had monetary policy deviated from actual interest rate policies and considered a different starting period of its hiking cycle by following the model-consistent interest rate rule. We contrast these results

[3]Parallel policies involving other monetary instruments were also implemented from 2022 onwards, such as the termination of 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 the TLTRO III. We abstract from these additional elements in our analysis, in particular assuming that the balance sheet of the ECB evolves according to the real-time projection of APP/PEPP holdings, in 10-year equivalents, the effects of which are already incorporated in the projection baseline for macroeconomic variables.

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. This enables us to assess whether monetary policy could effectively tame the inflation surge and to provide some alternative benchmarks against which the actual policy conduct be evaluated. Finally, the simulation results yield stabilization metrics, enabling a normative analysis of the macroeconomic stabilisation trade-offs.

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

In a first step, we ask the counterfactual question of whether the timing of the hike matters. In particular, what would have happened to interest rates, output, and inflation had the ECB followed the estimated Taylor-type interest rate rule of the NAWM II at different points in time since 2021:Q4—when inflation began to increase—as opposed to maintaining the lower-for-longer policy until 2022:Q2 and raising interest rates aggressively thereafter.

We place ourselves in 2021:Q4, 2022:Q3, or 2024:Q1 and assume full knowledge of incoming data and the ECB's off-model baseline forecast from the December 2023 BMPE (which is based on market forward interest rates).[4] 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.

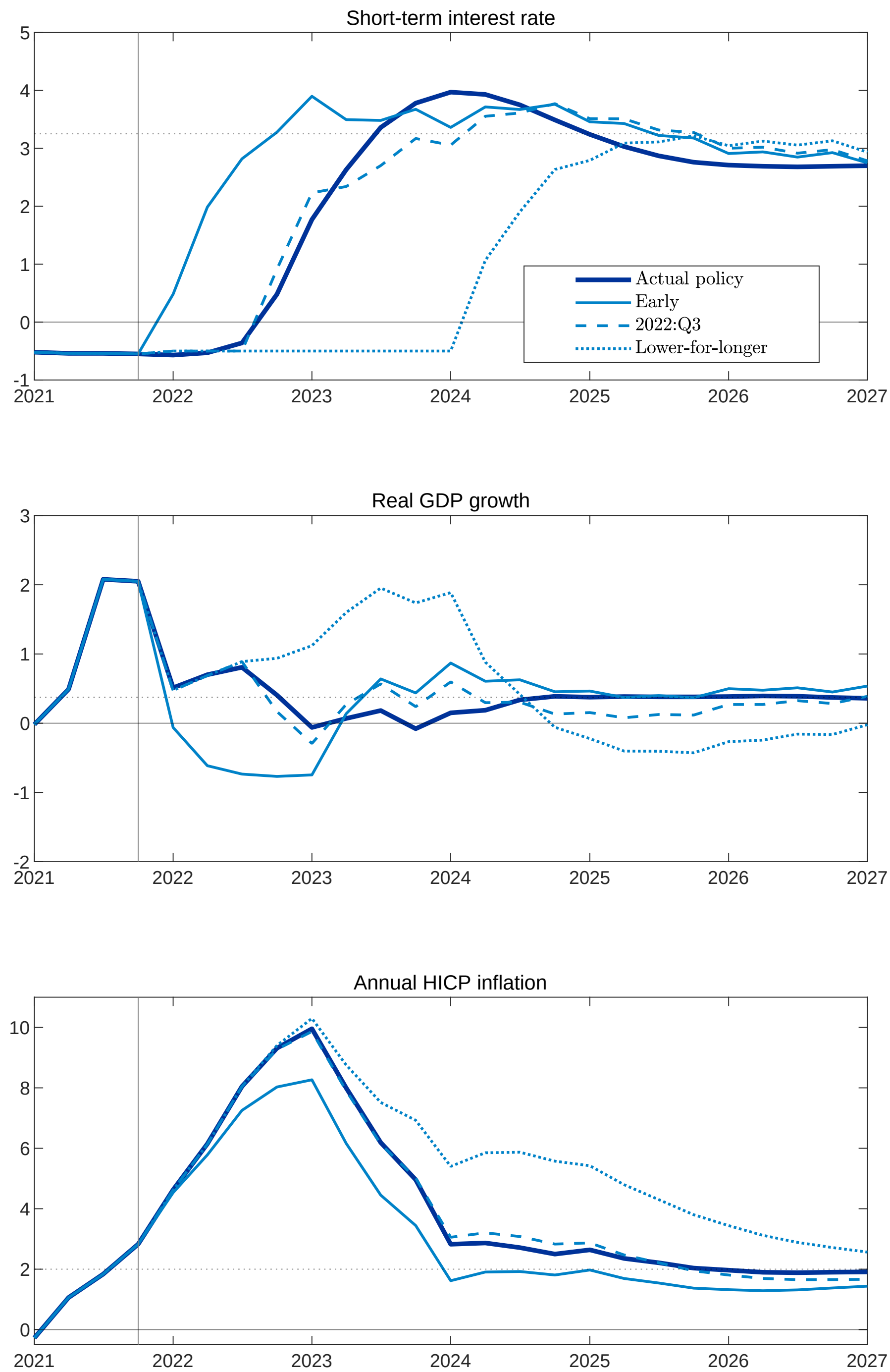
Specifically, the rule-based projection is implemented by performing a conditional forecast, starting in 2021:Q4, and conditioning on all structural shocks filtered from the baseline, other than the standard monetary policy shock. This allows taking into account all non-monetary structural shocks, that, according to the model, hit the economy between the starting date of the counterfactual simulation and 2023:Q4, such as global supply shocks, energy and food price shocks and the tightening of the labour market, but also all the subsequent shocks filtered from the December 2023 BMPE. 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.[5]

[4]In Section 3.3 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.

[5]In all exercises, we extend the off-model baseline beyond the projection horizon which is provided by an unconditional forecast using the Kalman filter.

Figure 2 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 2024:Q1 (dotted light blue lines), compared with historical data and baseline projections (solid dark blue lines).

Figure 2: Rule-based counterfactuals in 2021:Q4, 2022:Q3, and 2024:Q1



Note: This figure depicts rule-based counterfactual policies 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 2024:Q1 (dotted light blue lines), conditional on the December 2023 macroeconomic projection baseline (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 recession in 2022 and the first half of 2023. Annual HICP inflation, in turn, would have increased by less, 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 be 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 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, by delaying monetary tightening, the economy would have grown significantly above potential between 2022:Q2 and 2025:Q1, but at the expense of high and persistent inflation, which would have peaked around 10.5% and remained above 4% until 2026 due to higher inflation expectations and more pronounced second-round effects.

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, plunging 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.

3.2 What would optimal interest rate policy prescribe?

While the conditional forecast with the model-consistent interest rate rule allows gauging the effects of alternative starting dates of the hiking cycle, a second natural question that arises is, to what extent these monetary policy strategies are optimal, from a loss function minimization perspective. To answer this question, we compute an optimal interest rate path at different points in time, which is endogenously determined by means of minimizing an intertemporal loss function consistent with the central bank price stability orientation over the medium term.

Our approach consists of computing an optimal policy counterfactual under commitment conditional on the December 2023 macroeconomic baseline and a central bank loss function. The central bank commits *ex ante* to setting the short-term interest rate in a way that minimises a quadratic loss function approximating consumer utility, which penalises deviations of inflation rates from price stability, deviations of GDP from potential output, and interest rate volatility.[6]

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)), de Groot et al. (2021) or Harrison and Waldron (2021). Formally, the loss for strategy j, between t and $t+h$ is defined by:

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

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 stabilisation can be interpreted as reflecting central bank policy preferences. Being agnostic on these values, we calibrate them such that the 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. This calibration effectively renders the loss function consistent with market-expectations of monetary policy con-

[6] We implement the optimal policy counterfactuals by employing the COPPs toolkit by de Groot et al. (2021) in Dynare (Adjemian et al. (2022)).

duct.[7] Starting from a value of $\lambda_\pi = 1$, the benchmark calibration yields $\lambda_y = 0.5$ and $\lambda_{\Delta i} = 4$. Besides, we consider a "hawkish" calibration of central bank preferences, setting $\lambda_y = 0.1$.[8]

Figure 3 depicts optimal policy counterfactuals at different points in time and under both the "benchmark" and "hawkish" central bank preferences[9]. As in section 3.1, we assume the policymaker has full knowledge of the incoming data and the December 2023 macroeconomic projection baseline (solid dark blue line). 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.

Specifically, the optimal policies announced in 2021:Q4 (solid red or yellow lines) prescribe 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. For both policy preferences, 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.

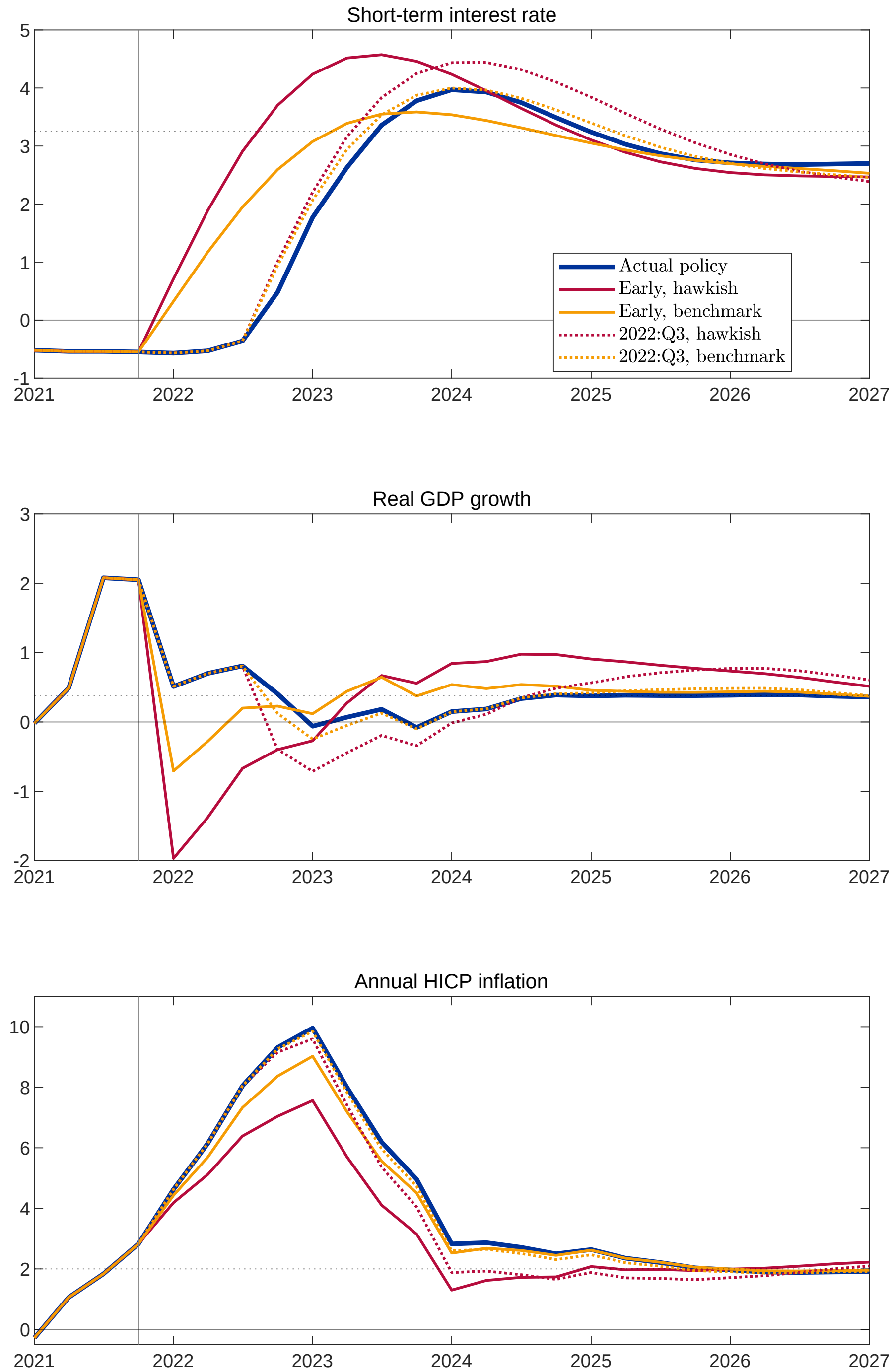
In turn, when optimal policy is implemented in 2022:Q3 (dotted red and yellow lines) the paths for the policy rate are less gradual and their peaks range between 4% and 4.25% reflecting that the higher inflation rates have already materialised at the time of policy shift. By calibration design, the benchmark 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

[7]As with the rule-based policy counterfactual, we assume that the policymaker adjusts only the short-term interest rate, while central bank asset holdings decline in line with market expectations and its effects are included in the macroeconomic projection baseline.

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

[9]To attenuate the forward guidance puzzle, in line with de Groot et al. (2021), we assume that only 80% of private-sector agents are attentive to policy announcements. We relax this assumption in section 4.3, where we repeat the exercise under alternative assumptions about expectation formation, namely, finite planning horizons, imperfect credibility, and learning.

Figure 3: Optimal policy projections in 2021:Q4 and 2022:Q3



Note: This figure depicts the optimal policy counterfactuals at different points in time and under alternative parameterisations of the central bank loss function conditional on the December 2023 macroeconomic projection baseline (solid dark blue lines). Solid red lines (solid yellow lines) represent the optimal policy in 2021:Q4 with hawkish (benchmark) preferences. Dotted red lines (doted yellow lines) represent the optimal policy in 2022:Q3 with hawkish (benchmark) preferences.

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.

3.3 Monetary policy counterfactuals in real time: ”Bad luck or bad policy?”

The medium-term orientation of monetary policy means that it is forward-looking and depends on the economic outlook: macroeconomic projections must therefore be accurate to adequately calibrate policy. In practice, unexpected macroeconomic shocks lead to forecast errors, and render policy suboptimal ex-post. For instance, the Russian invasion of Ukraine in 2022:Q1 and the war since then caused persistent supply disruptions and an increase in energy prices. Had the ECB forecast this event and its economic effects in December 2021, this would have justified hiking interest rate earlier.

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 adjustment of monetary policy stance and the management of the ouptut-inflation trade-off compared with alternative monetary policy conduct) 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.[10]

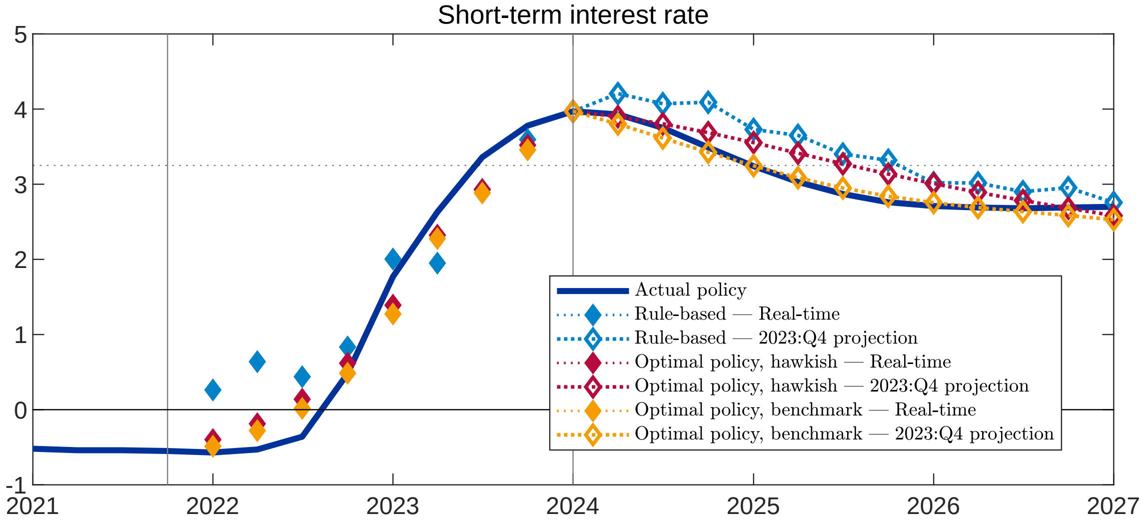
Figure 4 illustrates the comparison between actual policy and real-time staggered policy setting, using either the interest rate rule of the model (blue diamonds), or optimal policy with hawkish (red diamonds) and benchmark (yellow diamonds) preferences.

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. Unlike simulations with full information about the sequence of shocks hitting the economy between 2021:Q4 and 2023:Q4, 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 alterna-

[10]Figure 8 and 9 in the Appendix illustrate the quarterly vintages of projection baselines and counterfactual policy simulations.

Figure 4: 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. Policy projections are updated every quarter with the vintage of the relevant projection baseline (December 2021, March 2022, June 2022, September 2022, December 2022, March 2023, June 2023, September 2023, December 2023) and therefore include forecast errors. 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 loss function.

tive 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. At the same time, these projections are not as steep as the actual rate path. While policy rates normalisation appears to have been delayed in comparison to these real time projections, larger rate increments have at least partially counterbalanced the initial easing impulse.[11] For 2024 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.

3.4 Stabilisation metrics

Given the various monetary policy strategies evaluated so far, we next 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-

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

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:

$$\mathcal{V}_{expost,j} = \sqrt{\sum_{t}^{t+h} \beta^t \mathbb{E}_t (x_{t,j} - \bar{x})^2} \tag{3}$$

For the evaluation of *real-time* strategies, we take the average over quarterly macroeconomic and policy projections vintages from 2021:Q4 to 2023:Q4 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:

$$\mathcal{V}_{realtime,j} = n^{-1} \sum_{n} \sqrt{\sum_{t}^{t+h} \beta^t \mathbb{E}_t (x_{t,j} - \bar{x})^2} \tag{4}$$

Separately, we also report the welfare loss from each strategy, consistent with equation2, to assess to what extent various strategies affect consumer utility. Table 2 illustrates the results. Columns (1) to (3) present the volatilities 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 strongest benefits regarding 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 compared to actual policy. Considering the early implementation case, the output volatility is increased from 4 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 2, for all policy configurations. Assuming the *ex post* simulation protocol, it appears that the benchmark optimal policy improves upon the baseline, whatever the loss function is used in the evaluation. These improvements become nonetheless quite limited with a late implementation of the policy. The rule-based policy generally delivers worse outcomes, except in the early tightening case for the loss function with the hawkish preferences. Notice however that 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 prefer-

Table 2: 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	1.16	0.76
2022:Q3	1.00	0.97	1.06	1.01	1.01
2024:Q1 (LFL)	1.24	12.68	0.97	2.74	1.75
Optimal policy:					
early, benchmark	0.87	3.66	0.85	0.85	0.78
early, hawkish	0.68	10.06	1.16	1.26	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) deviation of the endogenous variable from its target level in the policy counterfactual. For instance, a value of 0.9 indicates a 10% improvement in the stabilisation of the policy target variable. Benchmark preferences: $\lambda_\pi = 1$, $\lambda_y = 0.5$, $\lambda_{\Delta i} = 4$. Hawkish preferences: $\lambda_\pi = 1$, $\lambda_y = 0.1$, $\lambda_{\Delta i} = 4$.

ences (against which the policy conduct is optimised): this policy would be 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 a prolonged recession lasting at least twice as long as in a scenario with hikes starting in 2021:Q4.

Turning to the real-time stabilisation metrics (last rows of Table 2), the inflation stabilisation or welfare improvements of the optimal policies become much 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.

4 Extensions

As the validity of the findings presented so far rely on the validity of the model itself, 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

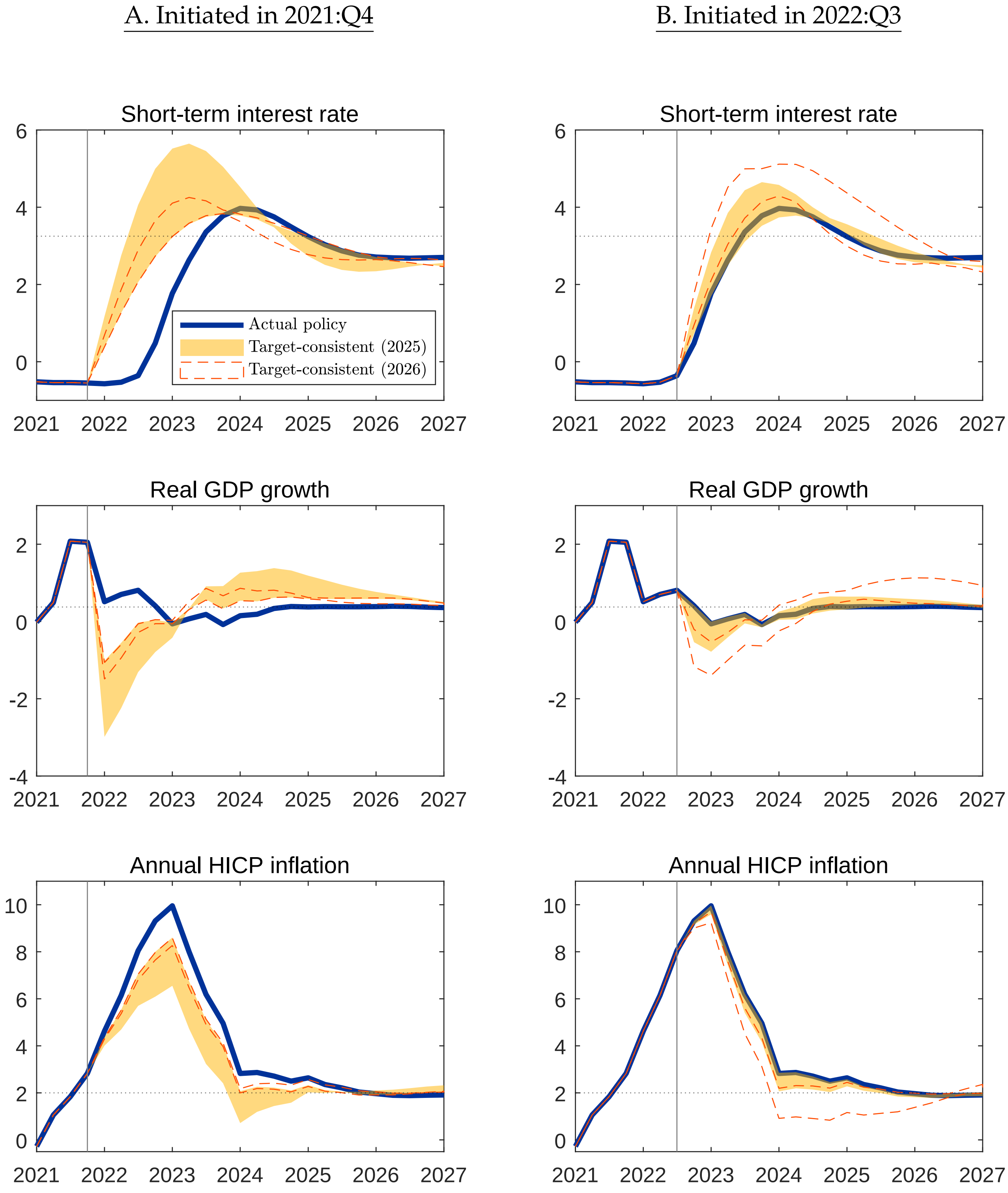
The calibration of the loss function utilised so far for optimal policy represent policymaker preferences that range from a balanced dual mandate approach ("benchmark") to a "hawkish" environment. To assess the robustness of our results to policymaker preferences we extend this range of central bank 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.[12]

Across these strategies, for a given starting date, some overlap enables the stabilisation of inflation at the target in both 2025 and 2026. However, beginning in 2021:Q4 allows for a lower peak of inflation in 2022, albeit at the cost of triggering a deep economic downturn. If the policymaker targets inflation in 2025, this may result in some undershooting of the target in 2024. Alternatively, delaying until 2022:Q3 reduces the scope to impact inflation in 2022 and 2023. To improve over the baseline, this necessitates a steeper rate path and a somewhat lower peak compared to

[12]Figure 10 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 (2025) and the longer term (2026). 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 avoid overshooting the inflation target.

Figure 5: Target-consistent strategies



Note: This figure depicts the optimal policy counterfactuals starting in 2022:Q3 conditional on the December 2023 macroeconomic projection baseline (solid blue lines). The loss function (eq. 2) is parametrised using the range of parameters contained in the white isocurves of Figure 10, that deliver target-consistent inflation in 2025 (yellow area) and 2026 (red dashed lines).

the policy initiated in 2021:Q4. Achieving the target inflation for 2026 requires more aggressive tightening compared to targeting 2025, potentially leading to a significant undershoot in 2025-26 before reaching the 2% target from below in 2026.

4.2 Parameter uncertainty

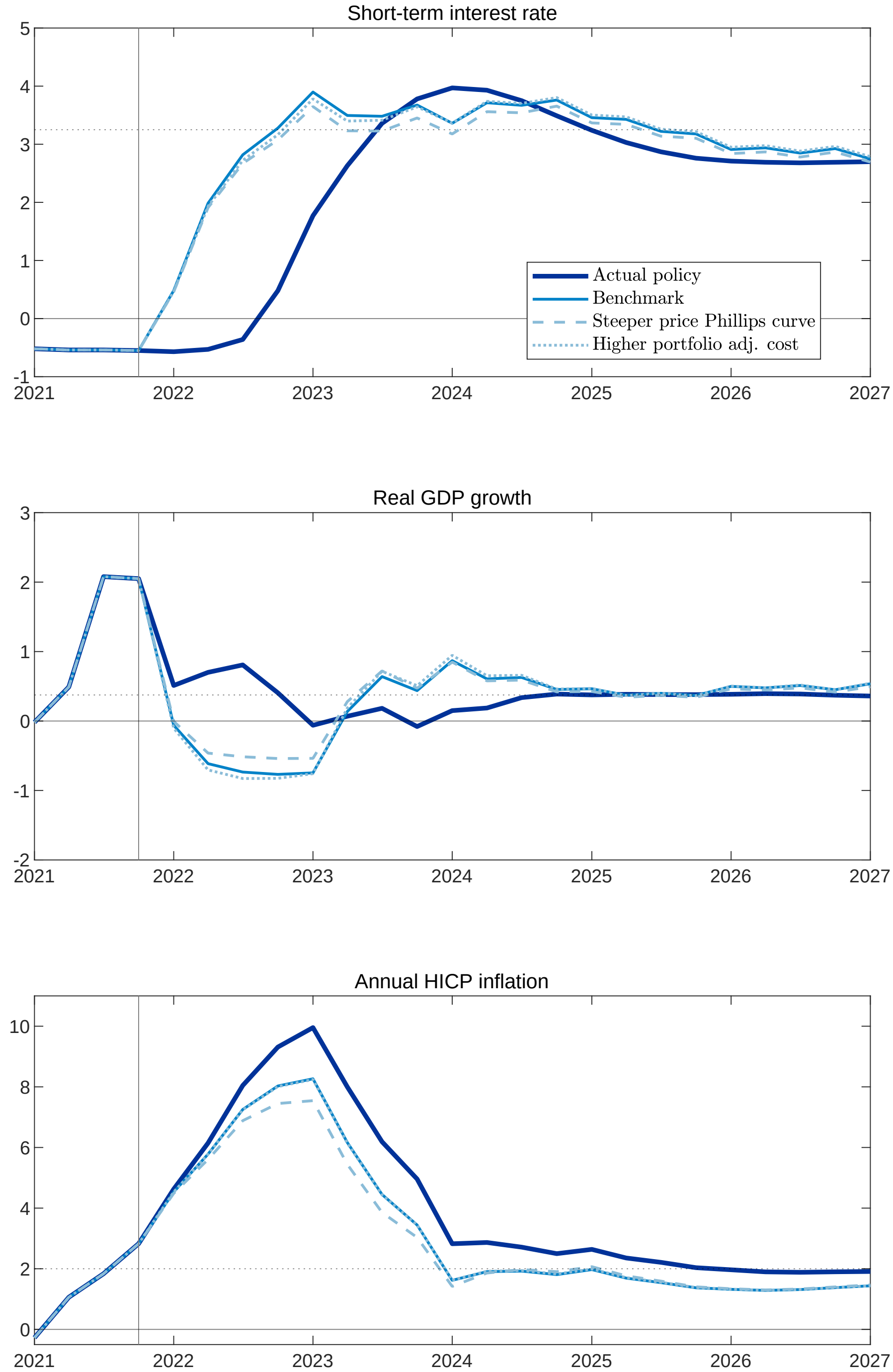
Next, we undertake robustness checks around key parameters of the model that dictate the transmission of shocks through the production structure and the financial sector. Given our focus on altering the model structure, for consistency, we focus on providing counterfactuals using the model-based interest rate rule. Figure 6 illustrates rule-based policy counterfactuals starting in 2021:Q4 under a steeper slope of the price Phillips curve (dashed light blue line) and a higher households' portfolio adjustment costs (dotted light blue lines), contrasting them against our benchmark (solid light blue lines).

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 restrictive monetary policy can induce greater disinflation with less 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. The results suggest that under this configuration 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.[13]

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 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

[13] This sensitivity captures instances of possible non-linearities reflecting a state-dependent Phillips curve and hence a stronger transmission of shocks in high-inflation regimes (see, e.g., De Santis and Tornese (2023)

Figure 6: Rule-based counterfactuals in 2021:Q4 with parametric sensitivity



Note: This figure depicts rule-based counterfactual policies whereby the ECB followed the historical reaction function since 2021:Q4 conditional on the December 2023 macroeconomic projection baseline, in models with alternative parametrisation of the slope of the price Phillips curve or the households' portfolio adjustment cost.

less flexibly to changes in excess bond returns. Overall, the degree of portfolio adjustment costs amplifies the effects of shocks in the model when financial intermediary balance sheet constrains tighten and the premium of long-term government bond increases.

To assess the robustness of our results 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 amplifies the response of economic activity to a monetary policy shock. An increase in the interest rate therefore amplifies the reduction in demand for long-term financing from 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, leading similar interest rates hikes to produce disinflation but at a higher output cost.

4.3 Private-sector expectation formation

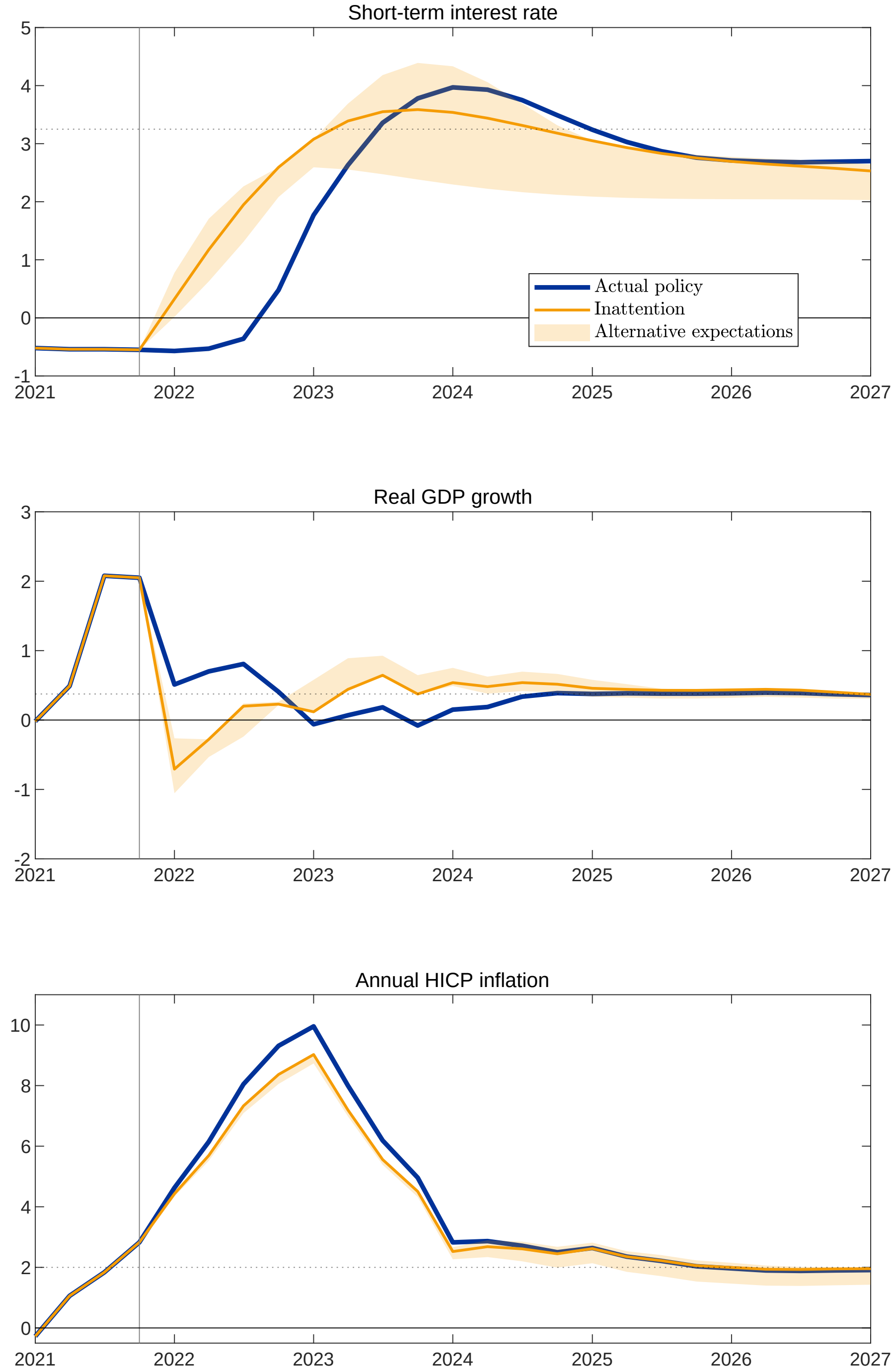
Optimal policy is implemented under commitment such that policy announcements about future policy affect the contemporaneous behaviour of agents via anticipated shocks. In models with rational expectations, these anticipated shocks may lead to implausibly strong effects on macroeconomic variables, the so-called "forward guidance puzzle". To attenuate the propagation of interest rate shocks in NAWM II, we have so far aligned the way in which agents in the economy form expectations to empirical estimates, by assuming that 80% of private-sector agents are attentive to policy announcements (Coenen et al. (2022)). 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 inattentive to them in addition to the model discount factor.

We next compute optimal policy under alternative expectation formation mechanisms, such as imperfect credibility, a finite planning horizon and learning, following the approach in de Groot et al. (2021). We assume that under imperfect credibility, the fraction of agents incorporating the policy shock decays in the horizon h of the announcement according to $\alpha^h = 0.8^h$. Instead, under finite planning horizons, 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, the degree to which anticipated policy shocks are integrated into expectations is defined by a two-parameter logistic function: $\beta_1 = 1$ defines the speed of learning about the policymaker commitment to its announcement, and $\beta_2 = 5$ defines the initial beliefs.

The results are summarized in Figure 7.[14] Under imperfect credibility, unlike under inattention, the share of agents incorporating the policy shocks into their expectations decays exponentially with the policy horizon: policy announcements further away in the future are therefore even less effective under imperfect credibility than under inattention. At the current juncture, this would necessitate a lower peak rate than under inattention as agents would incrementally observe the

[14] Figure 11 in the Appendix presents the associated optimal policy projections for each type of alternative expectation formation mechanism.

Figure 7: Optimal policy projections in 2021:Q4, range of alternative expectation formation mechanisms



Note: This figure depicts alternative policy counterfactuals conditional on the December 2023 macroeconomic projection baseline (solid blue line). 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.

policy easing impulse, relative to the baseline. Instead, under finite planning horizons, agents completely ignore policy shocks beyond 4 quarters ahead, implying a more gradual tightening and higher peak rates but less persistence in restrictive territory. Last, under learning, the attenuating function evolves over the simulation horizon, reflecting that agents learn to pay attention to policy announcements: in the first period, policy shocks are largely unanticipated, while in subsequent periods the degree of anticipation steadily increases. As a result, much of the tightening must be frontloaded.

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 New Area-Wide Model (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.

Using as benchmark the macroeconomic projection path of key variables produced by ECB staff, we simulated the effects on GDP growth and inflation under a strategy where interest rate policy follows the inertial Taylor-type rule at different points in time. The results suggest that the timing of the start of the hiking cycle matters for euro area macroeconomic dynamics. In hindsight, and with full information about the macroeconomic conditions that prevailed since 2021, an earlier hike would have minimised the peak of inflation and achieved convergence to the target faster. Instead, the forceful monetary tightening since 2022:Q3 attested to the credibility of monetary policy, preventing to some extent higher inflation from becoming entrenched and moderating the risk of second-round effects. Our results also suggest that the interest rate rule of the NAWM II tracks well actual policy, suggesting that the model's estimation captures the ECB's reaction function adequately.

hen comparing these full-information counterfactuals against real-time counterfactual policy, we conclude that based on the information set at the time, the policies employed were suitable for shaping inflation. Finally, optimal policy counterfactuals predict hump-shaped interest rate increases, with higher peak rates but less persistence of the restrictive stance.

Clearly, the validity of these counterfactual results depend on the validity of the model itself.

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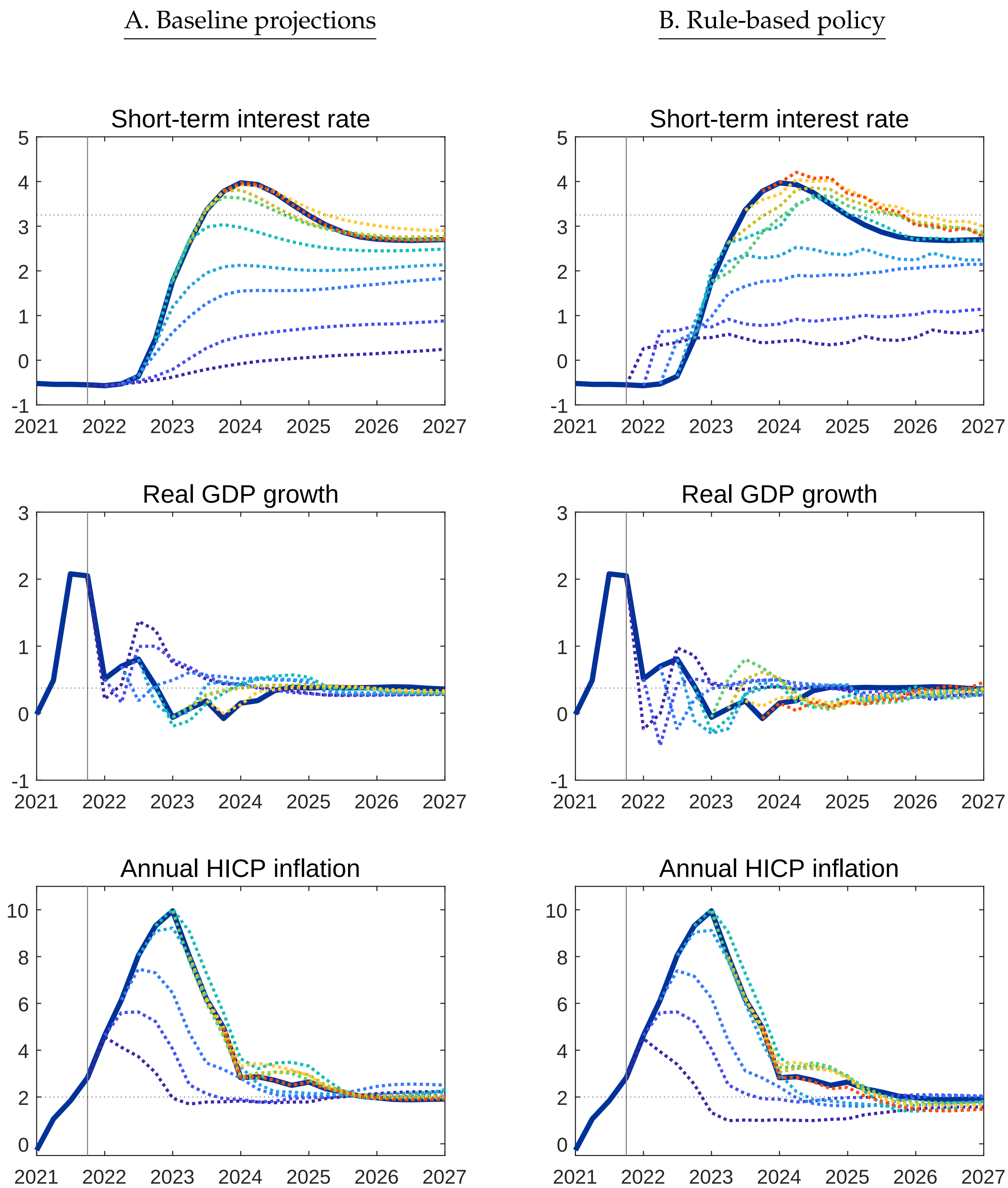
Appendix

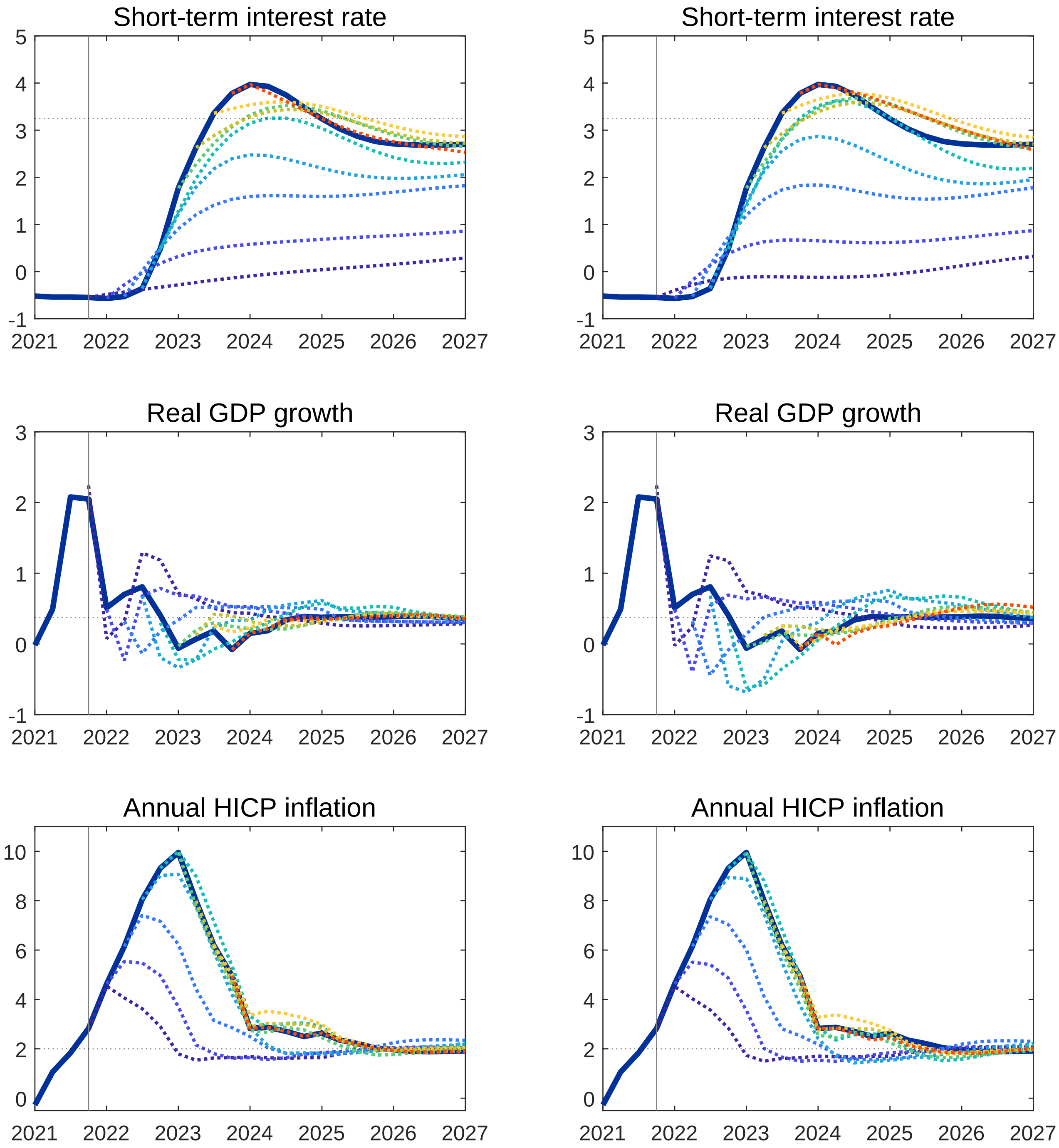
Figure 8: Real-time vintages between 2021:Q4 and 2023:Q4



Note: This figure depicts real-time rule-based counterfactual simulations (right) conditional on quarterly real-time macroeconomic projection baselines (left) of the ECB between 2021:Q4 and 2023:Q4. The rule-based paths are computed and updated each quarter by finding the policy path consistent with the feedback rule of the model.

Figure 9: Real-time vintages between 2021:Q4 and 2023:Q4

C. Optimal policy $\lambda_y = 0.5$ | D. Optimal policy $\lambda_y = 0.1$



Note: This figure depicts the optimal policy counterfactuals at different points in time and under alternative parameterisations of the central bank loss function conditional on quarterly real-time macroeconomic projection baselines of the ECB between 2021:Q4 and 2023:Q4.

Policy preferences Figure 10 depicts projected annual HICP inflation in 2025 (top row, Panels I and II) and 2026 (bottom row, Panels III and IV) under optimal policy counterfactual 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 $\lambda_{\Delta i}$.

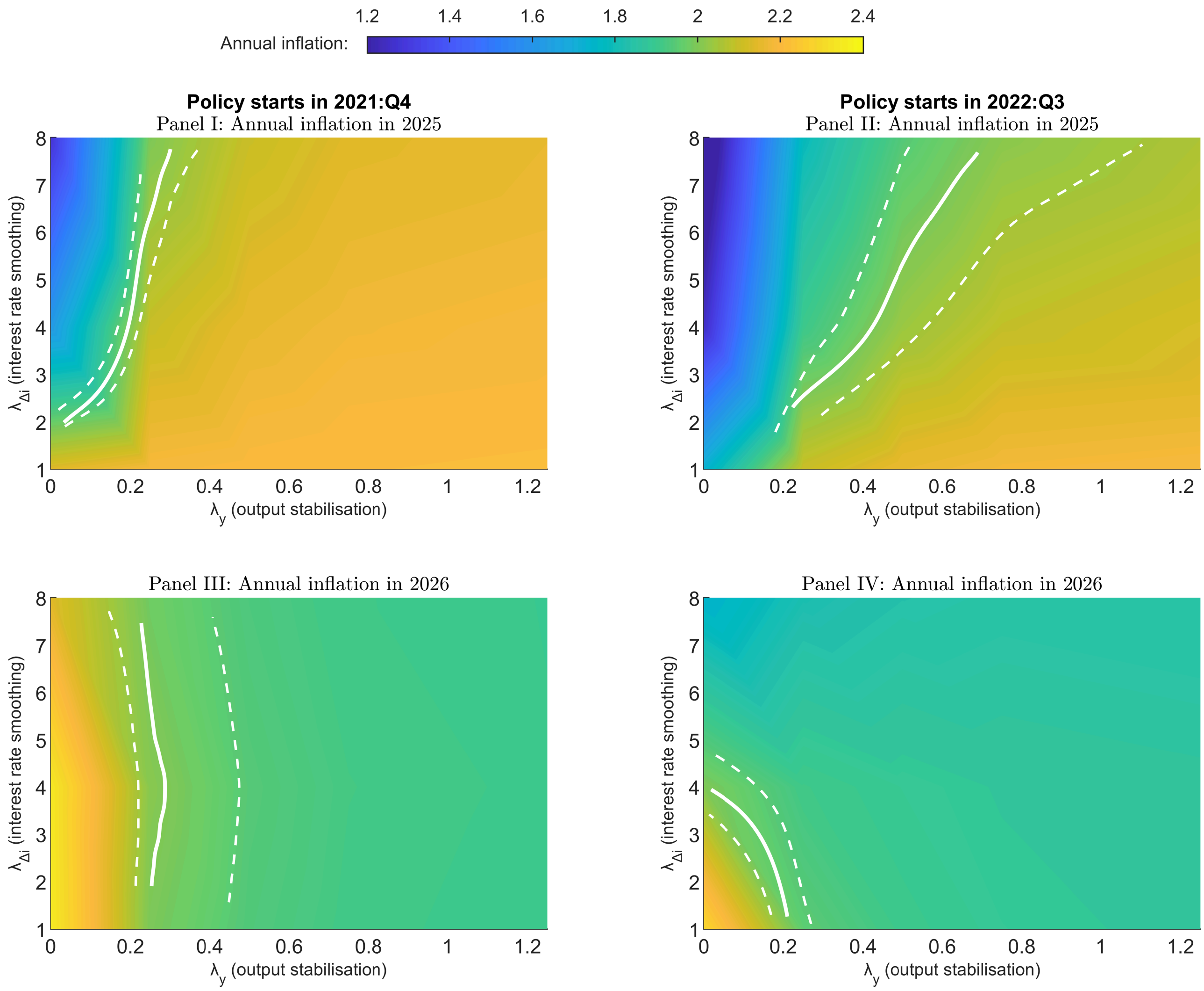
If policymakers define price stability over a three-year horizon (Panels I and II), there exists a positive relationship between the weight assigned to output and the interest rate smoothing parameter. Optimal policy with a greater emphasis on output implies increased consideration for inflation-output trade-offs. Given the nature of the supply shocks affecting the economy over that period, a more gradual tightening initially must be offset by greater persistence at the peak level: a higher rate smoothing parameter further delays the initial tightening sequence but enables the delivery of an appropriately restrictive stance within the policy horizon. This is valid whether the hiking cycle starts in 2021:Q4 or 2022:Q3.

Postponing the starting date of the hiking cycle to 2022:Q3 instead results in a reduction of the policy horizon by three quarters. Lags inherent to monetary policy transmission entail a more moderate tightening impulse overall to mitigate the risk of falling below the inflation target in 2025, consistent with a higher weight attached to output; all else equal, the isocurve shifts to the right. Overall, such a strategy allows reaching the target in 2025 with reduced macro-financial volatility.

If policymakers instead define price stability over a longer horizon (Panel III and IV), the relationship between the two parameters is negative. To achieve the target on average in 2026 when initiating the hiking cycle in 2021:Q4, the weight on output should fall between 0.2 and 0.3, irrespective of the value of the rate smoothing parameter, exhibiting only a slight negative correlation for higher values of the rate smoothing parameter. The two isocurves for the hiking cycle starting in 2021:Q4 intersect at point (0.24, 6.75) and would yield 2% inflation both in 2025 and 2026.

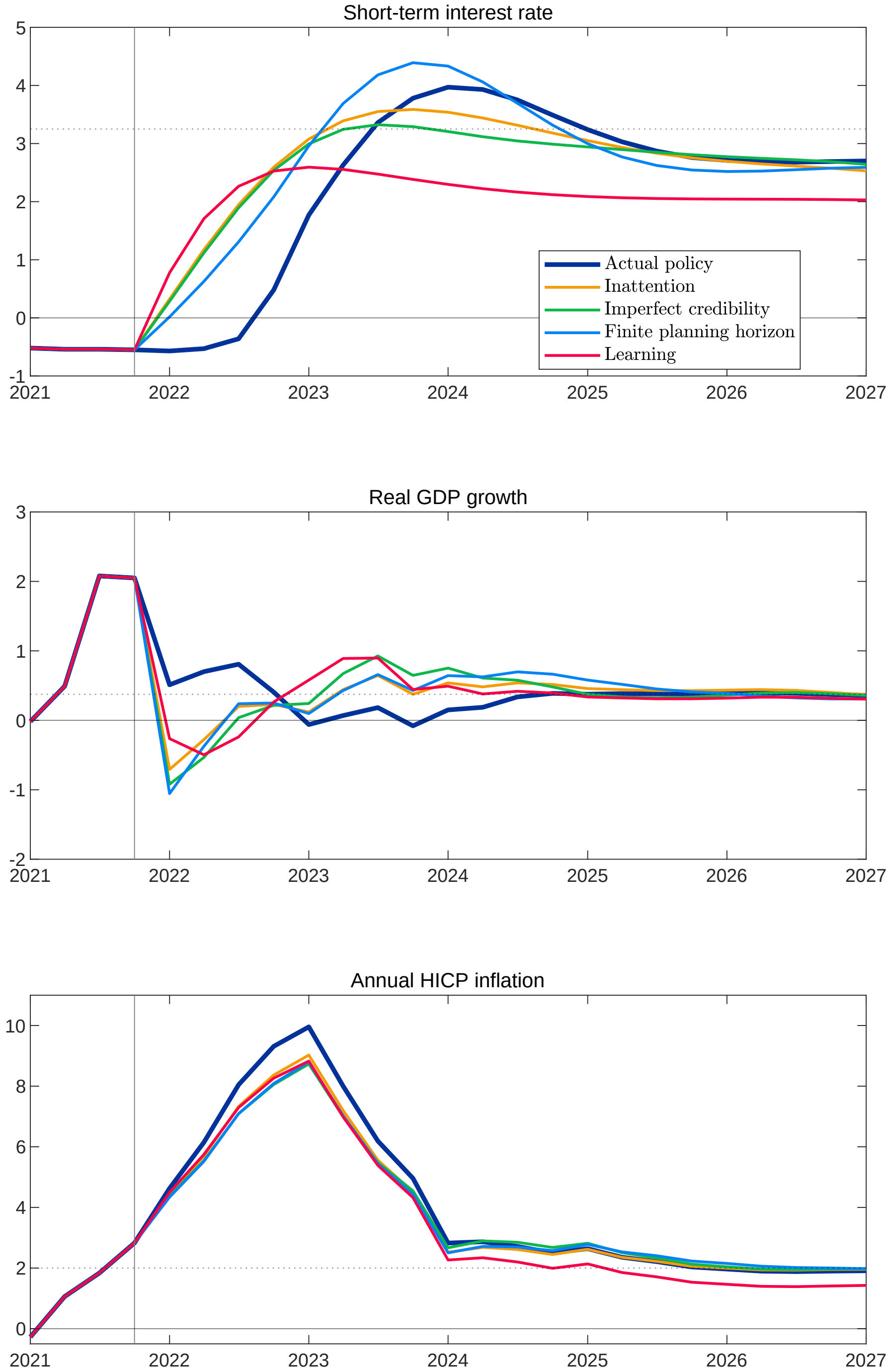
To achieve the target on average in 2026 when initiating the hiking cycle in 2022:Q3, the weight on output is decreasing with the rate smoothing parameter: a lower weight on output necessitates a higher rate smoothing to increase persistence at the peak level and avoid overshooting the inflation target in 2026.

Figure 10: Policy preferences consistent with medium-term price stability



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) conditional on the December 2023 macroeconomic projection baseline. Each panel is constructed using several alternative combinations of parameter values for λ_y and $\lambda_{\Delta i}$ for a given weight on price stability $\lambda_\pi = 1$. The pairs of parameters delivering 2% inflation in 2025 and 2026 are interpolated linearly.

Figure 11: Optimal policy projections in 2021:Q4, alternative expectation formation



Note: This figure depicts alternative policy counterfactuals conditional on the December 2023 macroeconomic projection baseline (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 areas include the range of other private-sector expectation formation mechanisms: imperfect credibility, finite planning horizons and learning.

Acknowledgements

This paper is a companion to Ciccarelli et al. (2024), an ECB occasional paper documenting modelling capabilities and applications in the Forecasting and Policy Modelling Division of the ECB.
The views ex-pressed in this paper are those of the authors and should not be attributed to the European Central Bank or the Eurosystem. For valuable comments and suggestions we thank seminar and conference participants at the European Central Bank.

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PDF ISBN 978-92-899-6683-2 ISSN 1725-2806 doi:10.2866/806632 QB-AR-24-052-EN-N