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MONETARY POLICY TRANSMISSION IN THE EURO AREA: IS THIS TIME DIFFERENT? CHAPTER I: LAGS AND STRENGTH

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Challenges for Monetary Policy Transmission in a Changing World Network (ChaMP)

This paper contains research conducted within the network "Challenges for Monetary Policy Transmission in a Changing World Network" (ChaMP). It consists of economists from the European Central Bank (ECB) and the national central banks (NCBs) of the European System of Central Banks (ESCB).

ChaMP is coordinated by a team chaired by Philipp Hartmann (ECB), and consisting of Diana Bonfim (Banco de Portugal), Margherita Bottero (Banca d'Italia), Emmanuel Dhyne (Nationale Bank van België/Banque Nationale de Belgique) and Maria T. Valderrama (Oesterreichische Nationalbank), who are supported by Melina Papoutsi and Gonzalo Paz-Pardo (both ECB), 7 central bank advisers and 8 academic consultants.

ChaMP seeks to revisit our knowledge of monetary transmission channels in the euro area in the context of unprecedented shocks, multiple ongoing structural changes and the extension of the monetary policy toolkit over the last decade and a half as well as the recent steep inflation wave and its reversal. More information is provided on its website.

Monetary Policy Transmission in the Euro Area: Is this Time Different? Chapter I: Lags and Strength

Andrejs Zlobins†

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Abstract

This paper documents the transmission of conventional monetary policy (MP) shocks over the period of two decades of the euro area's existence. First, we estimate a linear Bayesian structural vector autoregression (SVAR) and show that it takes approximately 12 – 18 months for the MP shock to fully transmit to both output and headline inflation. However, the transmission lags to the core and services inflation are longer, with full pass-through requiring more than 2 years. This implies that the impact of policy rate hikes implemented in 2022 and 2023 are still unwinding and will further contribute to disinflation of these HICP items. We then extend the SVAR system to allow for time-variation in both the parameter space and shock volatilities to pin down potential changes in the transmission mechanism. Time-varying impulse response functions reveal that the impact on output has been broadly stable over time. However, the reaction of inflation to policy rate hikes has been much stronger and more persistent in the recent tightening cycle, suggesting an exceptionally low sacrifice ratio. Finally, we rationalize those findings in a medium-scale New Keynesian DSGE framework. Model simulations suggest that two factors have contributed to the stabilisation properties of monetary policy: a forceful central bank response to the inflation surge and an increase in the frequency of price changes. While frictions related to wage-setting and real rigidities have likely had only minor implications concerning the effectiveness of monetary policy in the recent tightening cycle.

Keywords: monetary policy, transmission lags, sacrifice ratio, price-setting, euro area

JEL Codes: C54, E31, E50, E52, E58

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1 Introduction

The unprecedented surge in prices following the Covid-19 pandemic-induced supply chain disruptions and the Russian invasion of Ukraine led the European Central Bank (ECB) to embark on a tightening cycle, during which interest rates were hiked by 450 basis points (bp) cumulatively. This episode has been characterized by an abrupt shift to a high-inflation regime after nearly a decade of below-target inflation in the euro area and a return to conventional interest rate-setting following the deployment of several unconventional monetary policy measures during the ELB era. This has sparked a debate in regards to the macroeconomic effectiveness of those rate hikes compared to past regularities given the nonlinearities in the Phillips curve (Benigno and Eggertsson (2023), Cavallo et al. (2023), Karadi et al. (2024)) and a build-up of excess liquidity (Fricke et al. (2024)). The uncertainty surrounding the lags and strength of monetary policy pass-through to aggregate output and prices dates back to the famous dictum of Friedman (1961):

> *"Monetary actions affect economic conditions only after a lag that is both long and variable."*

Nonetheless, it is still present in contemporary policymaking as evidenced by a recent ECB Monetary policy statement (4 May 2023):

> "*At the same time, the past rate increases are being transmitted forcefully to euro area financing and monetary conditions, while the lags and strength of transmission to the real economy remain uncertain.*"

Such uncertainty concerning the lags of monetary policy transmission though is not unfounded. Recent literature has shown that monetary policy can affect economic activity within months. For example, Buda et al. (2023) show that consumption reacts strongly just one quarter after the shock. while employment is more inertial. These observations confirm Friedman's prediction that lags are heterogeneous with respect to the economic indicator of interest. Price formation, however, appears to respond more sluggishly to monetary policy announcements. Allayioti et al. (2024) focus particularly on the transmission of the ECB's monetary policy to prices, suggesting that the pass-through to highly sensitive core HICP items requires approximately 18 months with the effect being up to 3x stronger than for non-sensitive items. Aruoba and Drechsel (2024) also document monetary transmission to disaggregated price indices in the US. Their evidence suggests long lags of monetary policy to prices as the response of the headline price index turns significant only after 3 years.

This paper contributes to this literature by shedding light on the following aspects of conventional monetary policy pass-through in the euro area. It sets off by documenting the transmission lags to output and inflation over the two decades the euro area has existed. The robustness of linear estimates – obtained via structural vector autoregression (SVAR) – is then examined by considering a battery of different modelling choices – data frequency, identification strategy, alternative estimators of impulse response functions and controls for the omitted variable bias. Following that the paper focuses on the stabilisation properties of monetary policy in the recent tightening cycle by using a SVAR with time-varying parameters and covariance matrices to pin down potential changes in the transmission mechanism. Finally, the paper identifies key factors affecting the effectiveness of monetary policy in the post-pandemic environment and rationalizes the empirical findings in a medium-scale New Keynesian DSGE framework.

Overall, the empirical evidence, obtained via linear SVAR, suggests that it takes approximately 12 – 18 months for a conventional monetary policy shock to reach the peak impact on both output and headline inflation. However, transmission lags to more persistent HICP items, namely, core and services inflation are substantially longer as full pass-through requires more than two years to materialize. This implies that the impact of policy rate hikes implemented in 2022 and 2023 are still unwinding and will further contribute to disinflation of core goods and services prices, thus minimizing perils of stubbornly high price pressures in services to medium-term price stability. Furthermore, the time-varying impulse response functions indicate that the effect of recent rate hikes on inflation, both headline and core/services, has been much stronger as well as more persistent than in the past tightening cycles. More importantly, disinflation was achieved without excessive output loss and a rise in unemployment as the response of real GDP to monetary policy shock has been broadly stable over two decades of the euro area existence, suggesting an exceptionally low sacrifice ratio. Simulations via a medium-scale New Keynesian DSGE framework, containing most of the relevant nominal and real rigidities, provide the rationale for these empirical findings. In particular, model simulations suggest that two factors have contributed to a favourable trade-off for monetary policy stabilisation properties in the recent tightening cycle. First, a post-pandemic inflation surge has been characterized by a substantial increase in the frequency of price changes. This has direct implications for the transmission of monetary policy since an increase in the repricing frequency implies a steeper Phillips curve, thus lowering the sacrifice ratio. Second, a forceful and persistent monetary policy response to the inflation surge contained an up-side de-anchoring of inflation expectations, preventing incorporation of second-round effects into prices by firms. At the same time, we also document that frictions related to the wage-setting or real rigidities have likely only had minor implications for the effectiveness of recent policy rate hikes.

This paper proceeds as follows. Section 2 reviews the relevant literature. Section 3 describes the empirical framework, while Section 4 presents the empirical findings on the lags and strength of monetary policy transmission in the euro area. Section 5 lays out the medium-scale DSGE framework, while section 6 discusses the key factors affecting the monetary policy transmission in the post-pandemic environment. Finally, Section 7 concludes the paper.

2 Literature Review

This paper contributes to several strands of the literature. First, it builds on the vast literature studying the transmission of the ECB's monetary policy to the euro area economy (see Brand et al. (2010), Andrade et al. (2016), Altavilla et al. (2019), Jarociński and Karadi (2020), Leombroni et al. (2021), Buda et al. (2023), Grigoli and Sandri (2023), Allayioti et al. (2024) among others). Each of these papers measure the impact of the ECB's policy via high frequency changes in asset prices around the Governing Council announcements to track the propagation of policy impulse to financial markets, the real economy and price formation.

Studies leveraging granular data in particular challenge the conventional wisdom of long and variable lags, at least regarding the transmission to real activity. Buda et al. (2023) employ a daily series on real economic activity in Spain and state-of-the-art monetary policy shocks, inferred via high frequency changes in asset prices around the ECB policy announcements. They show that consumption and sales react strongly just one quarter after the shock while employment is more inertial. Additionally, they argue that the typical use of quarterly data to pin down the effects of monetary policy masks the short lags of economic activity, suggesting that temporal aggregation matters. Similarly, Grigoli and Sandri (2023) use daily transaction-level credit card data from Germany as a proxy for consumer spending and document how it responds to the high frequency monetary policy shocks identified by Altavilla et al. (2019). They show that conventional monetary policy surprises have a rapid pass-through to consumption, with a peak impact after two months. In addition they provide evidence of strong asymmetry in monetary transmission as easing surprises tend to have a very limited impact on consumer spending. Allayioti et al. (2024) on the other hand focus on the transmission of the ECB's monetary policy to prices by disaggregating the core HICP basket into interest rate-sensitive and non-sensitive items. Their estimates suggest that the pass-through to highly sensitive items requires approximately 18 months, with the effect being up to 3x stronger than for non-sensitive items. However, contrary to the evidence of short transmission lags to consumption, consumer prices do not exhibit statistically significant results in the short-run. This in line with the results from similar analysis for the US by Aruoba and Drechsel (2024) and aggregate-level results of Jarociński and Karadi (2020) for the euro area. That said, Allayioti et al. (2024) find evidence that the transmission of recent rate hikes has been faster and stronger than in the past.

The euro area economy has experienced a spell of large adverse shocks in the post-pandemic period, forcing an abrupt shift to a high-inflation regime after nearly a decade of below-target inflation. Recent literature has highlighted that such a shift gives rise to a state-dependent Phillips curve due to price-setting decisions (Benigno and Eggertsson (2023), Cavallo et al. (2023), Karadi et al. (2024)) and hence a stronger transmission of shocks in high-inflation regimes (e.g. De Santis and Tornese (2023) provides empirical evidence that the pass-through of energy supply shocks in the euro area is stronger in a high-inflation environment). Karadi et al. (2024) meanwhile provide theoretical foundations for a lower sacrifice ratio of monetary policy during a large surge in inflation. Using the state-dependent pricing setup of Golosov and Lucas (2007), they study the optimal monetary policy response to large cost-push shocks. Contrary to the conventional wisdom of "looking through" supply-side disturbances, they argue that a central bank should aggressively stabilise inflation in case of large shocks and leverage the lower sacrifice ratio of monetary policy as a large increase in costs induces firms to reset their prices more often, increasing the slope of the Phillips curve. We contribute to this strand of the literature by providing empirical evidence of monetary policy stabilisation properties in an environment when inflation is driven substantially above the target by extensive supply-side disturbances.

3 Empirical framework

In this section, we describe the econometric models used to measure the transmission lags and effectiveness of the ECB's conventional monetary policy actions and track their changes over time.

As our baseline setup, we employ a standard workhorse macro-econometric model – a structural vector autoregression. Let y_t for t = *1, . . . ,* T denote a vector of endogenous variables, evolving according to:

$$y_t = Cx_t + A_{1,t}y_{t-1} + ... + A_{p,t}y_{t-p} + \epsilon_t \tag{1}$$

where C is an $n \times m$ matrix, x_t is an $m \times 1$ vector of constants, A_j (j =*1, . . . ,* p) is an $n \times n$ array of coefficients related to the *j-th* lag. ϵ_t is an $n \times 1$ structural error vector with zero mean and variance-covariance matrix Σ while T denotes the sample size. We estimate the model with Bayesian methods by specifying an independent normal-Wishart prior distribution, which assumes that the matrix containing VAR coefficients A_j is multivariate normal:

$$A_j \sim N(A_{j0}, \Omega_0) \tag{2}$$

where coefficient mean A_{j0} is an $m \times 1$ vector and Ω_0 is an $m \times m$ diagonal coefficient covariance matrix with variance relating endogenous variables to their own lags given by:

$$\sigma^2_{ii} = \left(\frac{\lambda_1}{l^{\lambda_3}}\right)^2 \tag{3}$$

where λ_1 is a hyper-parameter that controls the overall tightness, l is the lag considered by the coefficient and λ_3 controls the relative tightness of the variance of lags, excluding the first one. The variance for cross-variable lag coefficients is given by:

$$\sigma^2_{ij} = \left(\frac{{\sigma_i}^2}{{\sigma_j}^2}\right)\left(\frac{\lambda_1\lambda_2}{l^{\lambda_3}}\right)^2 \tag{4}$$

where σ^2_i and σ^2_j denote the OLS residual variances of an autoregressive model estimated for variables i and j and λ_2 is a hyper-parameter that controls the cross-variable weighting. Finally, the variance for the constant is given by:

$$\sigma^2_c = {\sigma_i}^2(\lambda_1\lambda_4)^2 \tag{5}$$

where λ_4 is a hyper-parameter governing the exogenous variable tightness. In our case, we specify the prior using standard values for the hyper-parameters, i.e. we set the AR coefficient of the prior to 0.8, overall tightness λ_1=0.1, cross-variable weighting λ_2=0.5, lag decay λ_3=2, and exogenous variable tightness λ_4=100. Turning to the prior for the residual covariance matrix Σ, we assume that it follows an inverse Wishart distribution:

$$\Sigma \sim IW(S_0, \alpha_0) \tag{6}$$

where S_0 is an $m \times m$ scale matrix for the prior and α_0 is the number of degrees of freedom. S_0 is obtained from individual AR regressions following Karlsson (2012):

$$S_0 = (\alpha_0 - m - 1)\begin{pmatrix} {\sigma_1}^2 & 0 & 0 & 0 \\ 0 & {\sigma_2}^2 & 0 & 0 \\ 0 & 0 & \ddots & 0 \\ 0 & 0 & 0 & {\sigma_m}^2 \end{pmatrix} \tag{7}$$

where the degrees of freedom are set to $\alpha_0 = m + 2$.

The posterior distribution of the reduced form parameters and the residual covariance matrix is obtained via the Gibbs sampler with a total number of 20 000 iterations with the first 10 000 discarded as burn-in.

However, impulse response functions generated via SVARs can potentially be biased, especially at medium and long horizons since a SVAR extrapolates longer-horizon impulse responses from the first p sample of autocovariances as put forth by Li et al. (2024). Local projections estimator of Jordà (2005) on the other hand generates impulse response functions for each horizon based on current covariates, thus addressing the risk of biased estimates at the cost of higher variance. Therefore, we also deploy local projections to cross-check our SVAR-based estimates of lags and strength of monetary policy transmission in the euro area:

$$X_{i,t+h} = \alpha_{i,h} + \theta_h MP_t + \phi_h(L) Z_{i,t-1} + u_{i,t+h} \tag{8}$$

where $X_{i,t+h}$ is the variable of interest, MP_t is an exogenous monetary policy shock, $Z_{i,t-1}$ is a vector of control variables (including lagged values of the variable of interest), $\phi_h(L)$ is a polynomial in the lag operator and $u_{i,t+h}$ is an error term.

Finally, we extend the SVAR as in equation 1 to allow for time variation both in the parameter space and shock volatilities to pin down potential changes in the transmission mechanism. For convenience, we stack matrices of SVAR coefficients from equation 1 into vector $\theta_t = (\mathrm{C}', \mathrm{vec}(\mathrm{A}_{1,t})', ..., \mathrm{vec}(\mathrm{A}_{p,t})')$. The time variation of coefficients is then assumed to evolve according to a random walk process:

$$\theta_t = \theta_{t-1} + \upsilon_t \qquad \upsilon_t \sim N(0, \Omega) \tag{9}$$

where υ_t is a white noise vector with block-diagonal covariance matrix Ω. Additionally, in order to allow the error covariance matrix to be period-specific, we introduce stochastic volatility in the model as follows:

$$\Sigma_t = F_t \Lambda_t F_t' \tag{10}$$

where F_t is a lower triangular matrix with a unit diagonal and Λ_t is a diagonal matrix with elements denoted by $\exp(\lambda_{i,t})$ and the log-volatilities $\lambda_{i,t}$ following the AR(1) process:

$$\lambda_{i,t} = \gamma \lambda_{i,t-1} + \nu_{i,t} \qquad \nu_{i,t} \sim N(0, \phi_i\ ) \tag{11}$$

where γ is a persistence parameter set to 0.8 for all volatilities and $\nu_{i,t}$ is a white noise error with variance ϕ_i. Contrary to adopting the random walk assumption of Cogley and Sargent (2005) and setting $\gamma = 1$, we choose a slightly lower value for γ, since the random walk assumption implies that shifts in volatility become permanent and it does not revert to its long-run value. Key macroeconomic variables like the real GDP and inflation will typically have higher volatility during recessions but will return to their long-run values once the economic turbulence calms down. We make the following assumptions about the prior distribution in our TVP-SVAR-SV:

$$\pi(\theta|\Omega) \;\sim\; N(0, \Omega_0) \tag{12}$$

$$\pi(f_i^{-1}) \;\sim\; N(f_{i0}^{-1}, \Upsilon_{i0}) \tag{13}$$

$$\pi(\lambda_i|\phi_i\ ) \;\sim\; N(0, \phi_0) \tag{14}$$

$$\pi(\omega_i) \;\sim\; IG(\frac{\chi_0}{2}, \frac{\psi_0}{2}) \tag{15}$$

$$\pi(\phi_i) \;\sim\; IG(\frac{\alpha_0}{2}, \frac{\delta_0}{2}) \tag{16}$$

where f_i^{-1} denotes the vector in the F^{-1} matrix containing the non-zero and non-one elements with mean f_{i0}^{-1} and covariance Υ_{i0} for i = 2, ..., n ω_i are diagonal entries in the Ω matrix with the χ_0 and ψ_0 denotes the hyperparameters governing the shape and scale of variance. In order to make the prior non-informative, we set χ_0=ψ_0=0.001. Similarly, α_0 and δ_0 are hyperparameters related to the variance of volatility which are set to α_0=δ_0=0.001. Parameters Ω_0, f_{i0}^{-1}, Υ_{i0} and ϕ_0 are set equal to their OLS estimates from a time-invariant SVAR.

3.1 Data and identification strategy

The benchmark specification of models includes five variables: Real GDP, HICP inflation, 3-month EURIBOR as a proxy for the policy rate, Euro Stoxx 50 equity prices and the EUR/USD exchange rate. However, we also expand the baseline specification with additional macroeconomic and financial variables, thus yielding a medium-scale Bayesian SVAR, to control for the omitted variable bias (see dataset description in the Appendix A). Regarding the data transformation, in the time-invariant SVAR and local projections all variables enter the models as log-levels $\times$ 100, except those expressed as percentages which enter the models without transformation. In case of a time-varying SVAR with stochastic volatility, all variables are included in the model as year-on-year (Y-o-Y) growth rates, except interest rates which enter the model in levels. For robustness, we employ both monthly and quarterly data so that our estimates of transmission lags are not subject to temporal aggregation bias as argued in Buda et al. (2023). Hence, models are estimated with a data sample from January 2002 to October 2023 or Q1 2002 to Q3 2023 when quarterly frequency is used. This choice is dictated by the availability of a shock series since the intra-day OIS data prior to 2002 are noisy as shown in Altavilla et al. (2019). Given that the period also includes the acute phase of the Covid-19 pandemic (March–July 2020), special attention is needed to treat the impact of these outliers on inference. Lenza and Primiceri (2020) show that the extreme volatility in the data from March to June 2020 has a considerable impact on the parameter estimates and shock volatilities, thus implying serious consequences for identification in the VAR models. In this paper, we follow Carriero et al. (2021), which, *inter alia*, suggests to introduce dummies in the months affected by the pandemic to soak up the excess volatility observed in this period, alleviating the impact of outliers on inference in VARs. Specifically, we include two Covid-19 related dummies as exogenous variables with the first dummy taking the value of 1 in March and April 2020 (Q2 2020 when quarterly data is used), while the second one - in May, June and July 2020 (Q3 2020). The lag structure is set according to the standard choice in the literature - 12 when models are estimated with monthly data and 4 when quarterly data are used. Only in the case of time-varying SVAR do we depart from this practice and use 2 lags due to a highly computationally intensive process of estimation.

Identification of a conventional MP shock is performed via a mixture of high frequency information with narrative sign restrictions as in Zlobins (2022) and Grüning and Zlobins (2023), which allows to control for the effects stemming from central bank information shocks and an array of unconventional monetary policy measures deployed at the effective lower bound (see Appendix B for details on the identification strategy). However, we also use the Target factor of Altavilla et al. (2019) and the MP shock of Jarociński and Karadi (2020) to make sure that our estimates are not driven by specific assumptions embedded in our high frequency identification approach. The shock series are then plugged directly into the SVARs, following the "internal instrument" VAR literature (Romer and Romer (2004), Ramey (2011), Barakchian and Crowe (2013), Plagborg-Møller and Wolf (2021)). IRFs to the MP shock are then generated via Cholesky decomposition by ordering the shock series first, as suggested by Plagborg-Møller and Wolf (2021).

On top of HFI shocks, we consider two alternative identification approaches to pin down the MP shock. First, a simple recursive Cholesky decomposition is used with the same ordering as stated in the beginning of this subsection and is motivated by the standard approach in the literature to order the policy rate after output and inflation, assuming that the central bank cannot contemporaneously react to aggregate shocks. Fast-moving financial variables on the other hand are ordered after the policy rate to allow for an instantaneous response to monetary policy shocks. Second, we utilize the sign and zero restrictions of Arias et al. (2018) to identify the MP shock alongside aggregate demand and supply shocks using the following scheme:

Shock	Real GDP	HICP inflation	3-month EURIBOR	Euro Stoxx 50	EUR/USD
Aggregate demand	-	-	0		
Aggregate supply	-	+	0		
Monetary policy			+	-	+

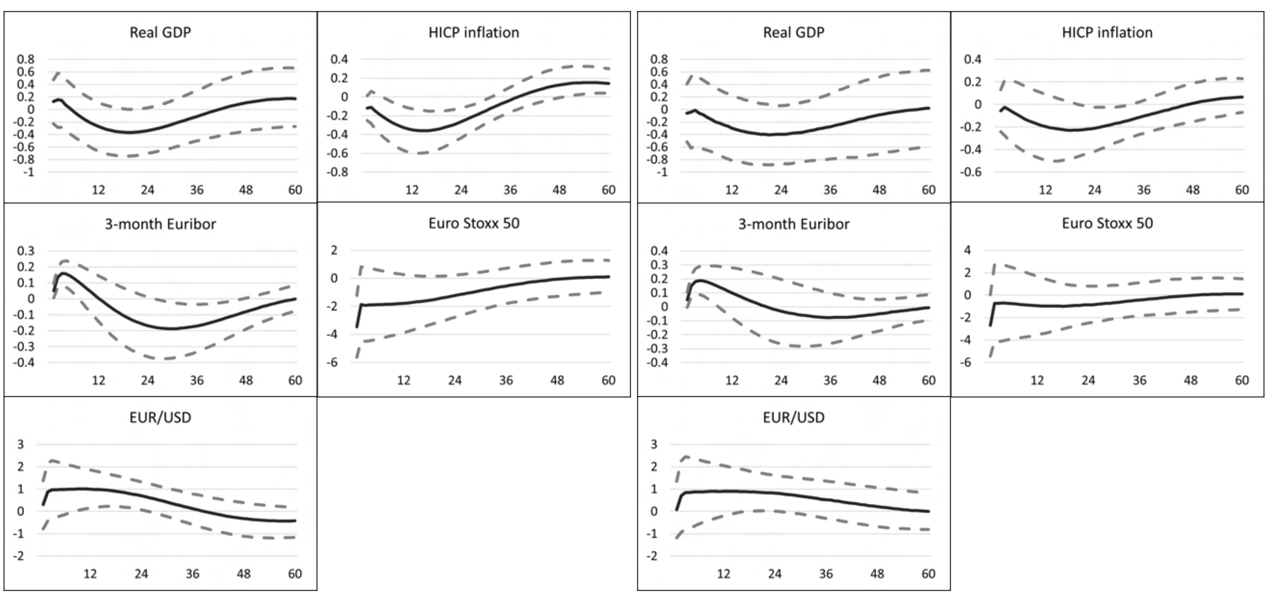
Note that the responses of output and inflation – our main variables of interest – are left unrestricted to avoid our estimates being driven by subjectively specified prior information, imposed via sign restrictions. We employ only uncontroversial restrictions on financial variables to pin down the effects of monetary policy, i.e. we impose a decrease in stock prices and exchange rate appreciation after a contractionary monetary policy shock. All restrictions are imposed to hold on impact only.

4 Empirical results

Figure 1 shows the baseline results from a linear SVAR estimated with monthly data, with panel (a) reporting results when the model is estimated with 12 lags and panel (b) – 6 lags to cross-check the impact of the lag structure. Results suggest that the choice of the lag length only has marginal impact on the estimates as the monetary policy shock requires approximately 18 months to reach the peak impact on output and 12 months for the inflation. Contrary to Buda et al. (2023) and Grigoli and Sandri (2023), we do not find significant real effects of monetary policy in the short-run; our results are more supportive of Friedman (1961) dictum of long and variable lags, since the financial variables tend to exhibit little-to-none lagged impact as they respond strongly on impact. It is also important to note that while the effects to a 5 bps hike in the policy rate might seem to be substantial, the estimated persistence of the MP shock is also large, as the 3-month EURIBOR continues to increase for several months after the initial shock, reaching a peak of $\sim$ 15 bps in the third month.

Figure 1: Baseline results with monthly data

(a) $p = 12$ lags **(b)** $p = 6$ lags

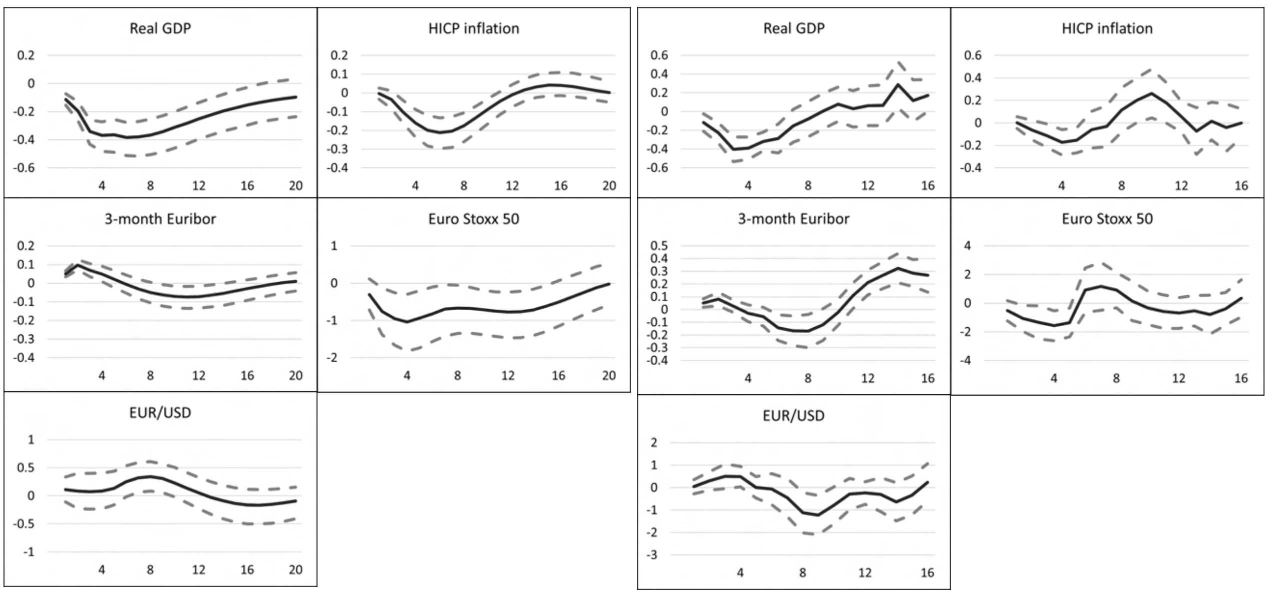


Note: Figures show impulse response functions from a Bayesian SVAR to the CMP shock, normalized to generate a 5 bps increase in the 3-month EURIBOR. The solid line shows the median response while the dashed region denotes the 68% credible sets.

Figure 2 shows the results from models estimated on a quarterly frequency, broadly confirming the baseline findings. In the case of the SVAR, the peak effect of conventional monetary policy shock materializes after 6 quarters for both output and inflation – in line with the estimates obtained with monthly data – suggesting that temporal aggregation doesn't significantly affect the profile of the impulse response functions. Local projections indicate a somewhat faster pass-through of monetary policy as the maximum effect arrives 3 – 4 quarters after the shock for both Real GDP and headline inflation. However, it is important to note that the impulse responses obtained via the SVAR in panel (a) also show that the effect one year after the shock is very close to the respective peak impacts. Furthermore, Figure 3 provides evidence that our estimates of monetary transmission lags

Figure 2: Baseline results with quarterly data

(a) Quarterly data **(b)** Local projections



Note: Figures show impulse response functions from a Bayesian SVAR and LPs to the CMP shock, normalized to generate a 5 bps increase in the 3-month EURIBOR. The solid line shows the median response while the dashed region denotes the 68% credible sets (in case of the SVAR) or 90% confidence interval (in case of the LPs).

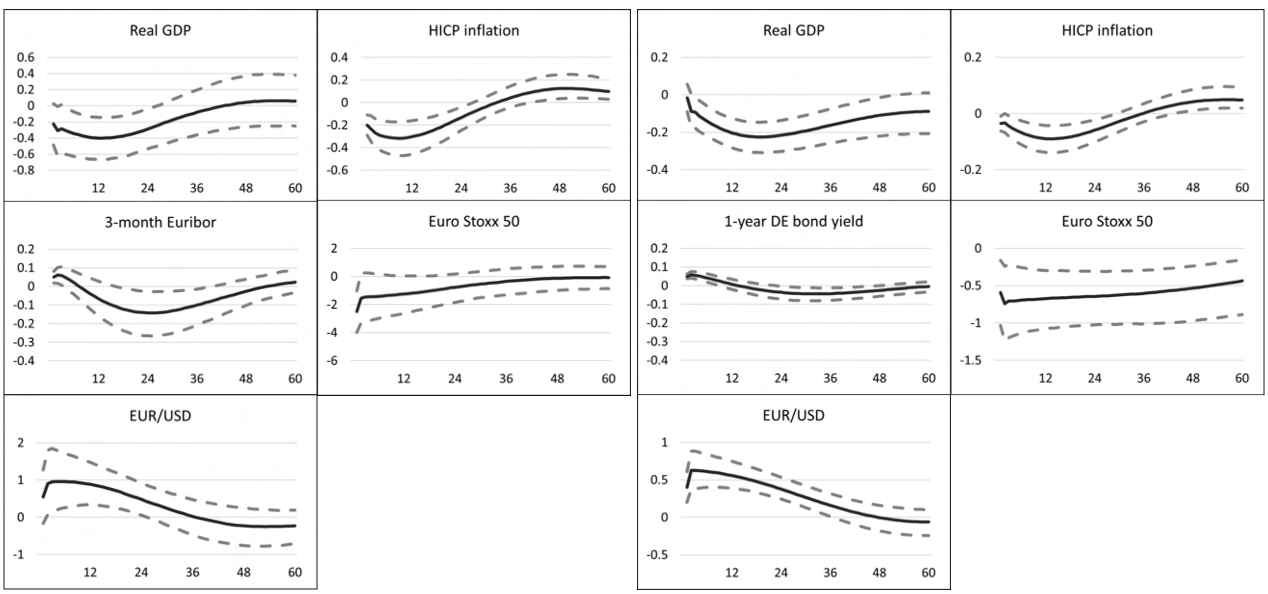
are not driven by specific assumptions in our identification of exogenous MP disturbance. Impulse responses to both the Target factor of Altavilla et al. (2019) and MP shock of Jarociński and Karadi (2020) are in line with our baseline estimates, suggesting that peak effects on output and inflation are observed within 12 – 18 months after the interest rates rise[1]. However, these results, as does the estimates obtained with the CMP shock and quarterly frequency in Figure 2, suggest that a sizeable pass-through of monetary policy to real activity in the short run cannot be disregarded.

[1] We use a 1-year DE government bond yield as a proxy for the policy rate instead of the 3-month EURIBOR when using the MP instrument of Jarociński and Karadi (2020) since it generates counterintuitive IRFs (see the results in the Appendix C. This also makes the choice of the policy proxy consistent with their setup.

However, the same cannot be said regarding the price formation, as only the impulse responses to the Target factor indicate the short-run effects of prices. In all other cases the response of inflation to monetary tightening is close to zero on impact. Figure 4 shows impulse responses to the monetary policy shock obtained via alternative strategies, with sign and zero restrictions approach delivering virtually identical estimates to those derived from using high frequency identification methods. A recursive Cholesky decomposition though suggests that real GDP and inflation respond to monetary policy actions with more delay as the peak effects are observed roughly two years after the initial impulse. This inconsistency with other identification approaches is driven by a substantially more persistent MP shock in the case when it is identified via the Cholesky decomposition since it takes approximately three years for the policy rate to return to the pre-shock level. The role of shock persistence is further explored in Section 6.

Figure 3: Robustness: different HFI shocks

(a) Target factor of Altavilla et al. (2019) **(b)** MP shock of Jarociński and Karadi (2020)

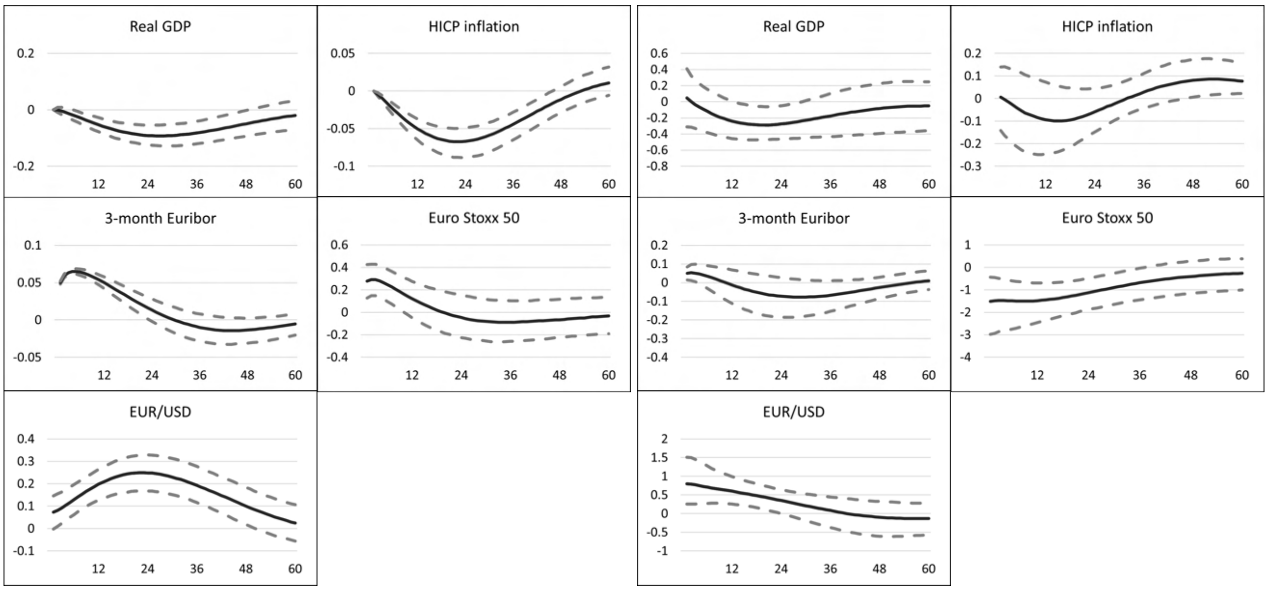


Note: Figures show impulse response functions from a Bayesian SVAR to the MP shock, normalized to generate a 5 bps increase in the 3-month EURIBOR or 1-year DE government bond yield. The solid line shows the median response while the dashed region denotes the 68% credible sets.

Finally, Figure 5 demonstrates that the baseline estimates don't suffer from the omitted variable bias. Extending the SVAR to include 15 key macroeconomic and financial variables does not markedly change the estimated transmission lags to real GDP and headline HICP inflation in the euro area. However, the medium-scale SVAR also allows for the exploration of transmission lags for a wider set of variables, including different HICP items. A recent surge in inflation has been

Figure 4: Robustness: other identification strategies

(a) Cholesky decomposition **(b)** Sign and zero restrictions



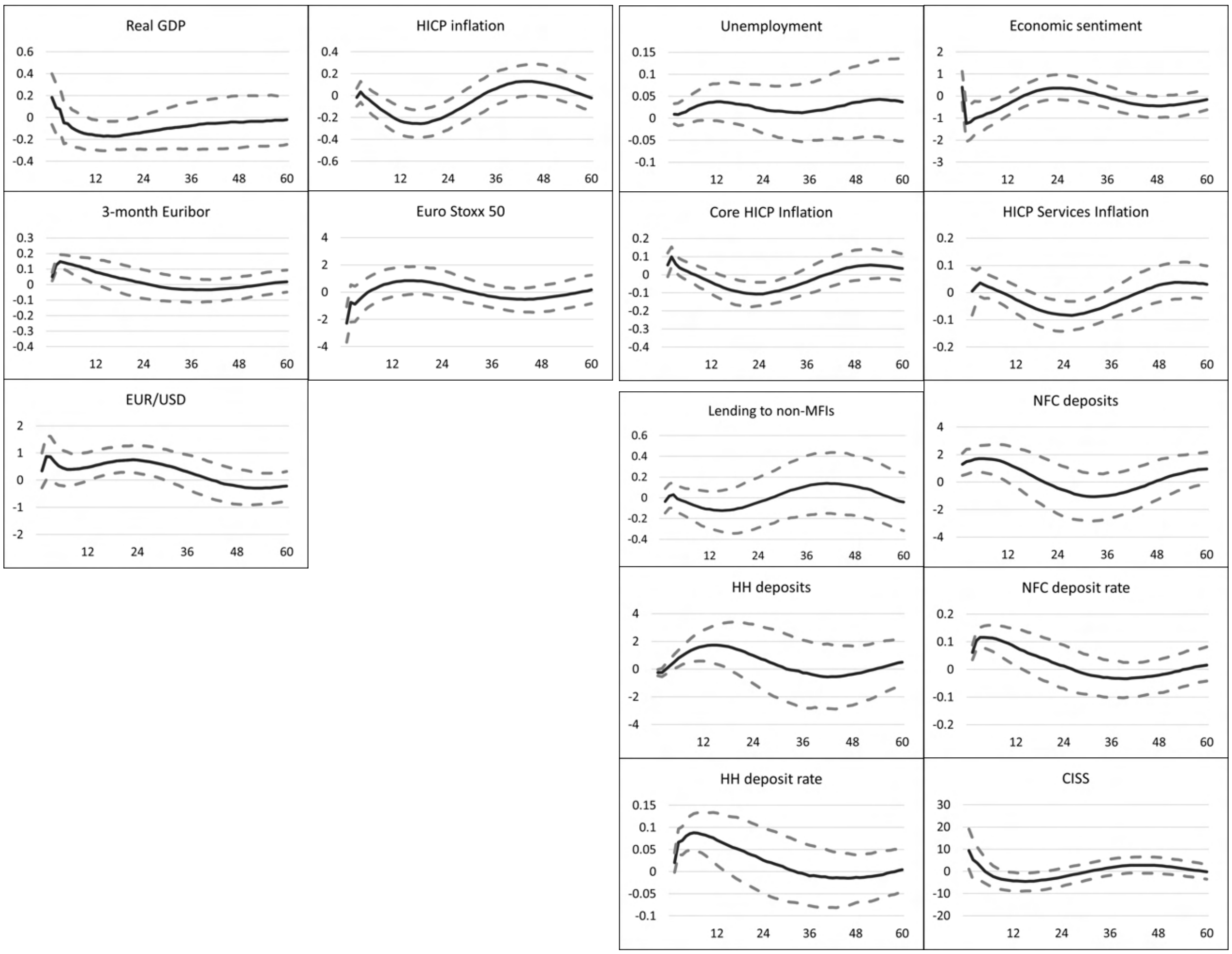
Note: Figures show impulse response functions from a Bayesian SVAR to the MP shock, normalized to generate a 5 bps increase in the 3-month EURIBOR. The solid line shows the median response while the dashed region denotes the 68% credible sets.

characterized by strong and very persistent price pressures in the services sector, causing a serious concern among the policymakers (see e.g. Schnabel (2023)) regarding the threat of sticky services inflation to medium-term price stability. Our evidence though suggests that transmission lags to core and services inflation are substantially longer when compared to headline inflation as the peak impact takes more than two years to materialize. Thus, the bulk of the impact from monetary tightening of 2022 and 2023 is still in the pipeline and will contribute to the softening of services prices in the coming years, minimizing the risks of sticky services inflation to medium-term price stability.

As regards other variables, unemployment responds broadly symmetrically to the developments in real GDP, with the peak effect occurring approximately one year after the shock, while the economic confidence indicator reacts almost instantaneously to monetary policy innovations. Similar heterogeneity can also be noticed among financial variables. Transmission to deposit volumes and rates generally takes place in the first year after policy tightening, with household deposits (both volume and rates) responding more sluggishly than firm counterparts. Lending is more slow-moving, with full pass-through requiring more than three years. The financial stress measure – CISS – on the other hand responds on impact, similarly to the Economic sentiment indicator. Thus, the

Figure 5: Robustness: medium-scale Bayesian SVAR

(a) Benchmark variables **(b)** Extended specification



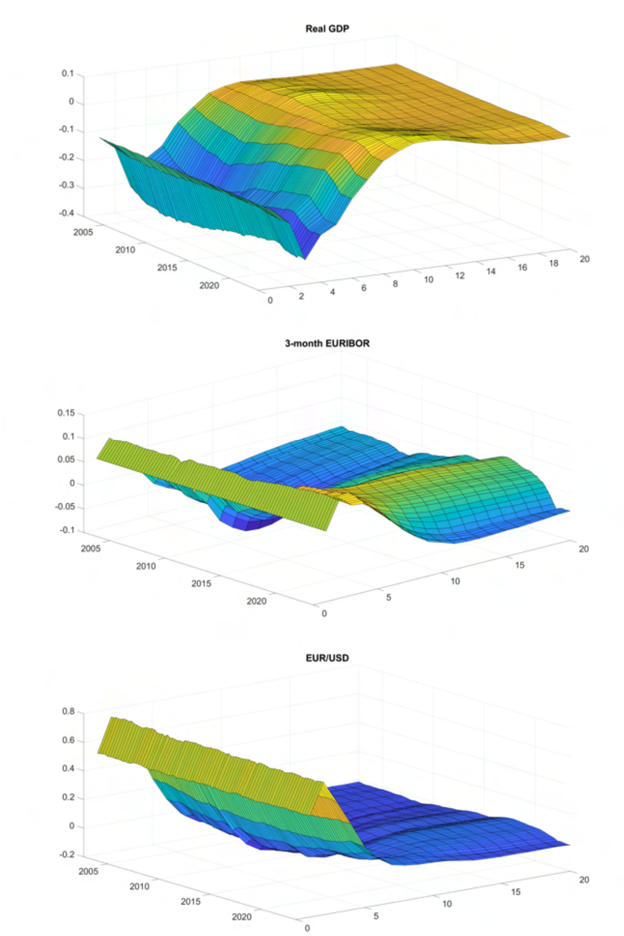
Note: Figures show impulse response functions from an extended Bayesian SVAR to the CMP shock, normalized to generate a 5 bps increase in the 3-month EURIBOR. The solid line shows the median response while the dashed region denotes the 68% credible sets.

linear evidence presented in this section is in line with the consensus that the transmission lags of monetary policy to the economy are very diverse. Nonetheless, we show that the results with respect to key variables of interest – real GDP and headline inflation – are robust to a wide array of stability checks. In the next subsection, we explore the role of non-linearities and focus particularly on the recent tightening cycle.

4.1 Is this time different?

In this subsection, we present the results from a SVAR, extended to allow for time variation both in the parameter space and shock volatilities. This permits us to pin down potential changes in the transmission of monetary policy to the euro area economy both with respect to lags and strength. This aspect is particularly important since the euro area in the last two decades has undergone structural changes (services deepening), confronted large shocks (the Great Recession, Covid-19 pandemic, and war-induced energy cost crisis), with ambiguous consequences for the slope of the Phillips curve, as well as the regime change in the monetary policy itself by relying on a suite of non-standard measures for the better part of the last decade due to the ELB, resulting in a build-up of excess liquidity.

Figure 6: Baseline results from the TVP-SVAR-SV



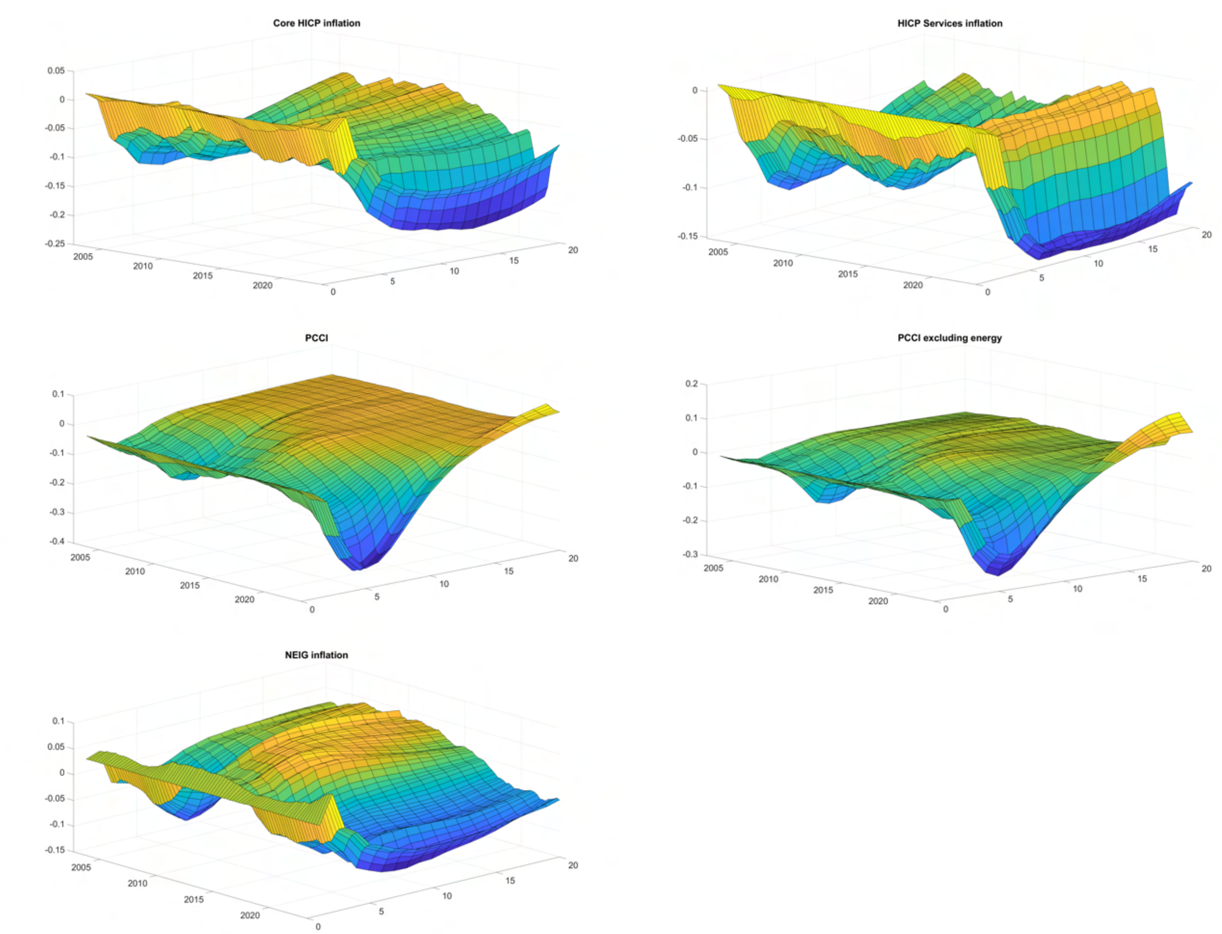
Note: Figures show impulse response functions from the TVP-SVAR-SV to the CMP shock over the period from Q3 2002 to Q3 2023. The shock has been normalized to a 5 bp increase in the 3-month EURIBOR in each period, allowing the estimated elasticities to be comparable over time. All variables are expressed as Y-o-Y growth rates except the 3-month EURIBOR, which enters the model in levels.

Figure 6 reports the time-varying impulse response functions to a conventional monetary policy tightening from Q1 2002 to Q3 2023. Non-linear evidence indicates that the response of the output has been broadly stable over time, with a slight decrease towards the end of the sample[2]. More

[2] In Appendix D, we show that dynamics of employment in response to monetary policy shocks has been similar

importantly, the impact on inflation has been much stronger and more persistent in the recent tightening cycle, implying a historically low sacrifice ratio. This is partly due to a much higher persistence of monetary policy shocks in the post-pandemic period, as demonstrated by the IRF of the 3-month EURIBOR, reflecting a forceful response of the ECB to the inflation surge. At the same time, financial variables – equity prices and the exchange rate – do not exhibit any time-varying behaviour.

Figure 7: Robustness: alternative measures of inflation in the TVP-SVAR-SV



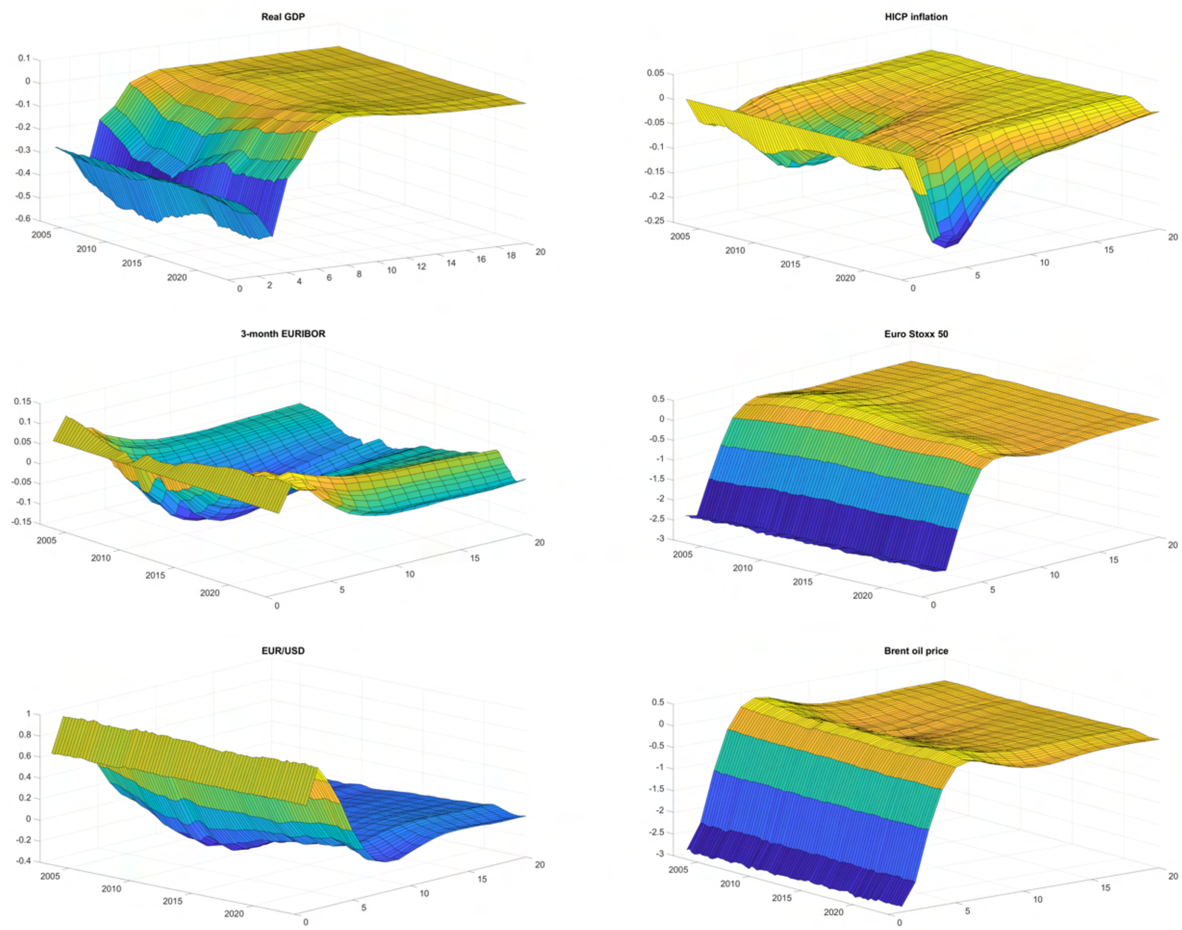
Note: Figures show impulse response functions from the TVP-SVAR-SV to the CMP shock over the period from Q3 2002 to Q3 2023. The shock has been normalized to a 5 bp increase in the 3-month EURIBOR in each period, allowing the estimated elasticities to be comparable over time. All variables are expressed as Y-o-Y growth rates except the 3-month EURIBOR, which enters the model in levels.

Figure 7 provides further evidence on a more powerful disinflationary impact of monetary policy during the post-pandemic inflation surge. We replace the headline HICP inflation with several measures of underlying inflation, namely core, services or NEIG HICP and PCCI, both the original

over time.

measure and a variant excluding energy. All trend inflation measures point to a substantially stronger pass-through of policy rate hikes in the latter part of the sample, confirming the robustness of this finding.

Figure 8: Robustness: controlling for cost-push shocks in the TVP-SVAR-SV



Note: Figures show impulse response functions from the TVP-SVAR-SV to the CMP shock over the period from Q3 2002 to Q3 2023. The shock has been normalized to a 5 bp increase in the 3-month EURIBOR in each period, allowing the estimated elasticities to be comparable over time. All variables are expressed as Y-o-Y growth rates except the 3-month EURIBOR, which enters the model in levels.

Another potential concern regarding our findings on a lower sacrifice ratio is that we do not control for the role of cost-push shocks, which have been among the key drivers of the post-pandemic inflation surge (Arce et al. (2024)). In order to verify that these developments are not misidentified with the disinflationary impact of monetary policy, we expand our baseline model specification to also include the Brent oil price as an endogenous variable in the model. Here we follow the recent literature (Ider et al. (2023), Miranda-Pinto et al. (2023)), documenting the transmission of monetary policy via energy prices, allowing us to capture this channel in our setup. Results in

Figure 8 confirm that supply-side induced disturbances to price formation have not affected the estimates of monetary policy transmission to inflation – they unequivocally point to a substantially higher pass-through in the post-pandemic environment. On top of that, the results remain robust when we replace our shock series with the MP shock of Jarociński and Karadi (2020) (see Appendix E), when the 3-month EURIBOR is substituted with other proxies for the policy rate (see Appendix F) and when linear SVAR, estimated over different sub-samples, is used instead of the TVP-SVAR-SV (see Appendix G). In the next section, we set up a medium-scale New Keynesian DSGE model to rationalize our empirical findings and pin down the factors which have affected the stabilisation properties of monetary policy in the post-pandemic environment.

5 Structural framework

In this section, we briefly describe our structural framework we use to rationalize the empirical evidence. Specifically, we deploy the New Keynesian DSGE model of Sims and Wu (2021), calibrated to the euro area as in Grüning and Zlobins (2023). Below we lay out the key ingredients of the model, for a full description of the model please refer to Sims and Wu (2021).

The model is a standard closed economy DSGE with a representative household and features most of the relevant nominal and real rigidities. Both wages and prices are rigid and subject to Calvo (1983) price- and wage-setting rigidity. The wages and prices can be partly indexed to past inflation if they are not allowed to be set optimally. The intermediate goods are produced with a standard Cobb-Douglas production function with capital and labour as inputs, subject to exogenous total factor productivity shocks. Building capital is subject to investment adjustment costs. Capital utilisation is endogenously chosen with lower capital utilisation leading to lower capital depreciation. The household sector allows for a representative household that maximises its lifetime utility by choosing the optimal consumption of final goods, subject to internal habit formation, and disutility from supplying labour. The fiscal authority consumes an exogenously specified amount of final goods (wasteful public consumption) by collecting the profits from the central bank, issuing public bonds, and levying a lump-sum tax on households. The public bonds supply is assumed to be fixed so that the lump-sum tax on households adjusts in such a way that the government budget constraint holds every period. The financial sector is modelled similarly to Gertler and Karadi (2011, 2013). The financial intermediaries finance the purchases of private and public bonds by issuing deposits to households and using their own net worth. Private bonds are issued by the final goods producer. Both types of bonds are assumed to be long-term bonds with a decaying coupon structure as in Woodford (2001). The financial intermediaries are subject to an incentive compatibility constraint so that they do not divert with a fraction of their assets. Shocking the fraction of their assets with which financial intermediaries could abscond with when the incentive compatibility constraint would not hold is a proxy for liquidity or credit shocks in the model. This absconding rate is allowed to differ for private and public bonds as a means to construct a spread between the private bond return to the public bond return. Every period a constant fraction of financial intermediaries must exit and transfer the remaining net worth to households. New financial intermediaries are born every period. They start their business with start-up funds from households. Differently from Gertler and Karadi (2013), financial intermediaries can also invest in interest-bearing reserves issued by the central bank. Moreover, the second constraint that financial intermediaries potentially face is a minimum reserve requirement.

The central bank's monetary policy tool set consists of conventional monetary policy, where the short-term nominal interest rate is set according to a Taylor-type interest rule with interest rate smoothing, endogenous adjustments to the inflation gap and the output gap, and exogenous monetary policy shocks. In normal times, this short-term nominal interest rate is equal to both the deposit interest rate and the interest rate on reserves. The zero lower bound (ZLB) constraint in the model implies that these three interest rates cannot become negative, unless the negative interest rate policy (NIRP) is employed as one of the unconventional monetary policy tools. The model includes a broad set of non-standard monetary policy measures – in addition to the NIRP, the central bank purchase assets via QE and provides forward guidance on the future rate path. However, since we focus on the transmission of conventional monetary policy in this paper, we do not discuss the implementation of non-standard measures in detail.

The model is calibrated to the euro area as in Grüning and Zlobins (2023). In essence, it follows the approach laid out in Section 4.1 of Sims and Wu (2021) but obtains information on the empirical moments for the euro area. However, for some parameters we adopt the parameters estimated by Coenen et al. (2018) using their New Area Wide Model II while for some of parameters we do not make any adjustments relative to the calibration of Sims and Wu (2021), since they have been set to conventional values in the literature and there is no divergent guidance from the literature for calibrations of models to the euro area. Specifically, in line with Gertler and Karadi (2011, 2013), the survival probability for financial intermediaries σ is also set to 0.95. The capital depreciation rate and the parameters governing the capital utilisation dynamics are left unchanged, relative to Sims and Wu (2021), and the same is true for the coupon decay parameter κ and the steady-state gross inflation Π. The labour disutility scaling parameter is chosen to adhere to the conventional choice to have a steady-state labour supply of $L = 1$.

As for the parameters borrowed from Coenen et al. (2018), we choose a slightly higher time discount factor of $\beta = 0.998$, a slightly lower habit formation parameter of $b = 0.62$, and a slightly higher share of physical capital in production $\alpha = 0.36$. In line with less flexible labour supply dynamics in the euro area compared to the US, the inverse Frisch labour elasticity is chosen to be 2 instead of 1. Due to the ECB having a single mandate as opposed to the Federal Reserve being obliged to a dual mandate, a larger weight is put on inflation in the Taylor rule, i.e. $\phi_\pi = 2.74$ instead of $\phi_\pi = 1.5$, and a smaller focus on the output gap, i.e. $\phi_y = 0.10$ instead of $\phi_y = 0.25$. The interest rate smoothing parameter is also higher in the euro area calibration, i.e. $\rho_r = 0.93$ instead of $\rho_r = 0.8$.[3] The largest changes to the parameters are, however, made to the wage and price rigidity calibration. There is now both wage indexation ($\gamma_w = 0.37$)[4] and price indexation ($\gamma_p = 0.23$)[5], slightly lower probabilities of being allowed to re-optimise the wage ($\phi_w = 0.78$) or to re-optimise the price ($\phi_p = 0.82$), and at the same time lower elasticities of substitution (i.e. higher mark-ups) for labour unions ($\epsilon_w = 1.3/0.3$ or a wage mark-up of $\epsilon_w/(\epsilon_w - 1) = 1.3$) and intermediate goods producers ($\epsilon_p = 1.35/0.35$ or a price mark-up of $\epsilon_p/(\epsilon_p - 1) = 1.35$). All the parameters are reported in Table 1. The model is solved via a linear approximation about the non-stochastic steady state. Following Sims and Wu (2021), exogenous MP shocks are turned off in the steady state, so that it only includes shocks to productivity, liquidity, and government spending. Thus, the IRFs only reflect the impact of the MP shocks as described in the next section since they are expressed relative to the scenario without any MP shocks.

[3] Note that the Taylor rule in Coenen et al. (2018) features two more terms: a term for adjusting the policy rate in response to a change in inflation and a term for adjusting the policy rate in response to a change in the output gap. We thus choose a Taylor rule and its calibration similar to theirs.

[4] Their value for wage indexation to inflation is chosen.

[5] Since the NAWM II model features several goods with several Calvo-style price rigidity calibrations, we have chosen to take their values for the price rigidity with respect to domestic prices for our calibration.

Table 1: Parameters for US and EA calibrations

Symbol	Description	US value/target	EA value/target
	Household sector and labour markets		
β	Time discount factor	0.995	0.998
b	Internal habit formation	0.7	0.62
η	Inverse Frisch labour elasticity	1	2
χ	Labour disutility scaling parameter	$L = 1$	$L = 1$
ϵ_w	Elasticity of substitution for labour types	11	1.3/0.3
ϕ_w	One minus probability to reset wage	0.75	0.78
γ_w	Wage indexation	0	0.37
	Production sector and price rigidity		
α	Physical capital share	0.33	0.36
δ_0	Steady-state capital depreciation rate	0.025	0.025
δ_1	Capital utilisation linear term	$u = 1$	$u = 1$
δ_2	Capital utilisation quadratic term	0.01	0.01
κ_I	Investment adjustment cost parameter	2	2
Π	Steady-state gross inflation	1	1
ϵ_p	Elasticity of substitution for intermediate goods	11	1.35/0.35
ϕ_p	One minus probability to reset price	0.75	0.82
γ_p	Price indexation	0	0.23
ρ_A	AR(1) persistence of productivity shocks	0.95	0.92
s_A	Volatility of productivity shocks	0.0065	0.007
	Fiscal authority		
$\bar{b}_G$	Steady-state government debt	$B_G Q_B/(4Y) = 0.41$	$B_G Q_B/(4Y) = 0.80$
G	Steady-state government spending	$G/Y = 0.2$	$G/Y = 0.204$
ρ_G	AR(1) persistence of government spending shocks	0.95	0.95
s_G	Volatility of government spending shocks	0.01	0.0035
	Financial sector and central bank		
κ	Coupon decay parameter	$1 - 40^{-1}$	$1 - 40^{-1}$
ψ	Fraction of investment financed by debt	0.81	0.50
σ	Financial intermediary survival probability	0.95	0.95
θ	General absconding rate	$400(R^F - R) = 3$	$400(R^F - R) = 3$
X	New financial intermediary start-up fund	Leverage = 4	Leverage = 4.6
Δ	Public bond relative absconding rate	1/3	2/3
ρ_t	AR(1) persistence of liquidity shocks	0.98	0.98
s_t	Volatility of liquidity shocks	0.04	0.04
ρ_r	Interest rate smoothing in Taylor rule	0.8	0.93
ϕ_π	Inflation gap parameter in Taylor rule	1.5	2.74
ϕ_y	Output gap parameter in Taylor rule	0.25	0.10
s_r	Volatility of monetary policy shocks	0	0
b_{cb}	Steady-state CB holdings of public bonds	0.06	0.1733
f_{cb}	Steady-state CB holdings of private bonds	0	0.0382
ρ_b	AR(1) persistence of public bond QE	0.8	0.8
ρ_f	AR(1) persistence of private bond QE	0.8	0.8

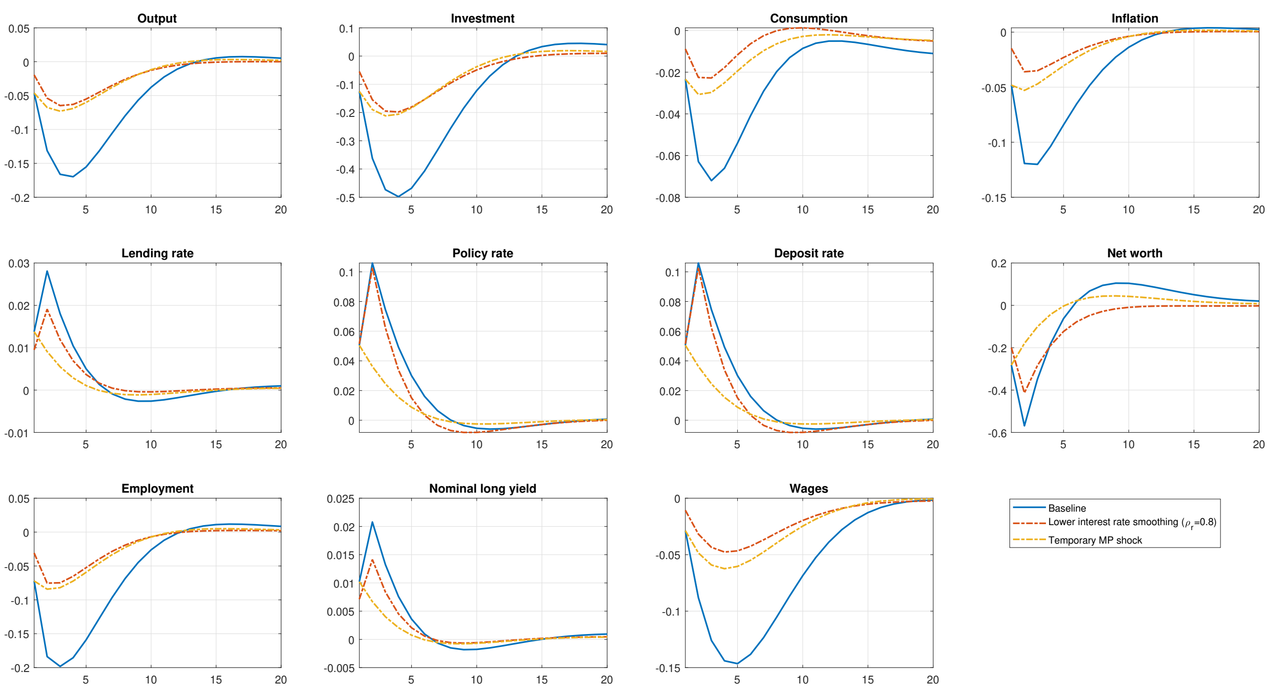
Notes: This table reports the parameters used in the calibration for the economy of the euro area. The original calibration of Sims and Wu (2021) is reproduced in column 3 to ensure comparability of our calibration to theirs.

6 Simulation results

In order to rationalize our empirical estimates of the lags and strength of conventional monetary policy in the euro area, we run a simulation with MP shocks in the DSGE model to roughly match the profile of empirical IRFs[6]. In particular, we shock the policy rate in the first two quarters to yield an increase in the interest rate by 5 bps on impact, rising to $\sim$ 10 bps in the second quarter.

Since our non-linear empirical results indicate much higher persistence of monetary policy shocks in the recent tightening cycle, we examine the role of the MP shock persistence by creating two alternative simulations. First, we assume that the MP shock is of a temporary nature, i.e. the policy rate is restricted to increase only in the first quarter. Second, we run a scenario with lower interest rate smoothing $\rho_r = 0.8$ instead of $\rho_r = 0.93$.

Figure 9: Exogenous conventional monetary policy shocks: the role of shock persistence



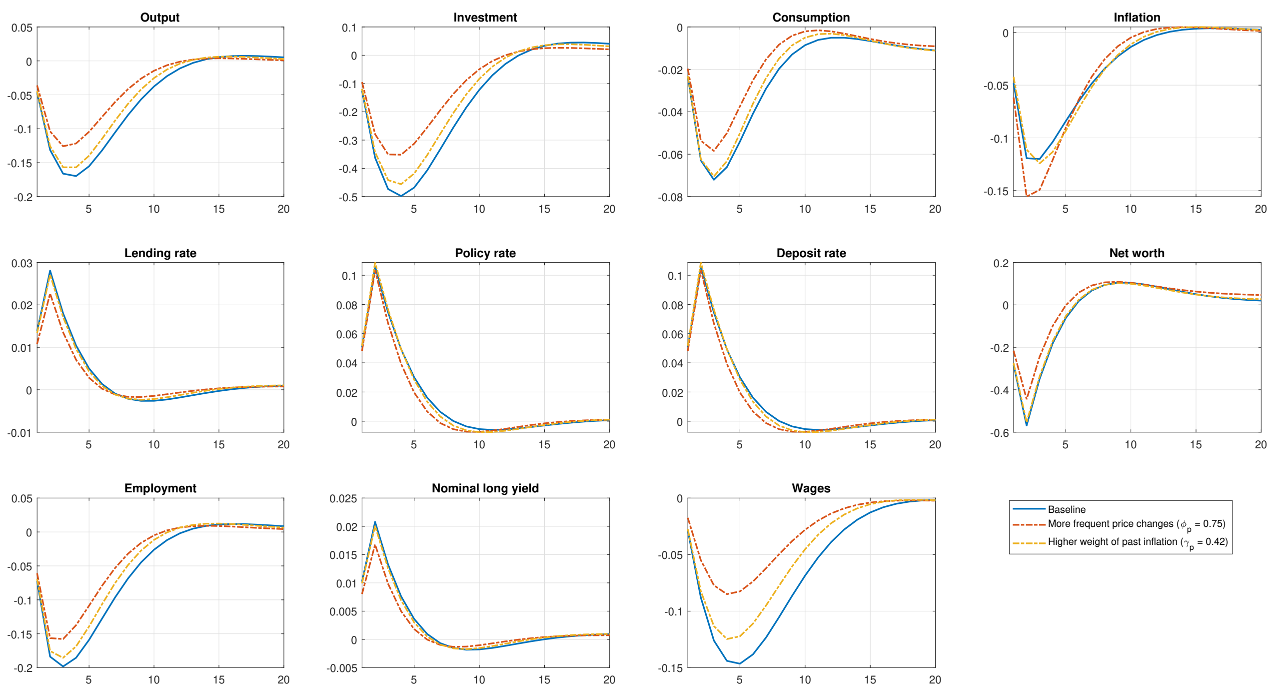
Note: Figures show impulse response functions to the conventional monetary policy shock. Blue lines depict the benchmark responses. Red lines: simulation assuming lower interest rate smoothing parameter in the Taylor rule, green lines: simulation with a temporary, one-off MP shock.

Figure 9 depicts the outcomes of these simulations. With respect to the baseline, our DSGE framework generates IRFs largely consistent with the empirical counterparts, both quantitatively and qualitatively as the model-implied responses fall within the credible sets of Bayesian SVAR

[6] Since the DSGE is calibrated to match empirical moments at quarterly frequency, we use empirical results from Figure 2 as a benchmark for structural simulations.

and transmission to output and inflation require 3-4 quarters. Alternative simulations, on the other hand, highlight the crucial role of the persistence of an MP shock – both sets of IRFs point to substantially lower stabilisation properties of monetary policy. While the forceful central bank response to the post-pandemic inflation surge has likely contributed to disinflation towards the target, as evidenced by non-linear estimates in Figure 6, it cannot explain the observed rise of the lower sacrifice ratio since the counterfactual simulations suggest that higher persistence affects output and inflation symmetrically.

Figure 10: Exogenous conventional monetary policy shocks: the role of price stickiness



Note: Figures show impulse response functions to the conventional monetary policy shock. Blue lines depict the benchmark responses. Red lines: simulation assuming more frequent price adjustments, green lines: simulation with a higher degree of price indexation.

The inflation surge in 2022 – 2023 following large energy-induced cost shocks has been characterized by a sizable increase in the frequency of price changes (Cavallo et al. (2023), Montag and Vallenas (2023), Dedola et al. (2024))[7]. An increase in the repricing frequency has implications for the price-setting modelling since the Calvo-style contracts assume constant frequency and, *inter alia*, also for the transmission of monetary policy as it implies a steeper Phillips curve. *Ceteris paribus*, the steeper the Phillips curve, the lower the sacrifice ratio of monetary policy stabilisa-

[7]See Appendix H for evidence from CPI microdata as reported in Dedola et al. (2024) on the repricing dynamics in the euro area during the inflation surge.

tion, since more flexible price-setting lessens the level of nominal rigidity in the economy and thus dampens the real effects of monetary policy. While the recent literature (see e.g. Cavallo et al. (2023), Karadi et al. (2024) among others) has deployed state-dependent pricing models to endogenize the response of repricing frequency to macroeconomic shocks, in this paper we instead rely on a canonical New Keynesian model with Calvo (1983) pricing. We capture this non-linearity by readjusting the parameters governing price-setting to pin down the extent to which more flexible price adjustments alter the transmission of exogenous monetary policy shock.

Recall the Calvo setup: in each period, a firm faces a constant probability $1 - \phi_p$ to reset its nominal price. Parameter ϕ_p therefore governs the aggregate price rigidity – lower value for ϕ_p causes frequency of price adjustment to rise. Firms that cannot set their prices optimally simply index to lagged inflation: $\phi_p \, \Pi_{t-1}^{\gamma_p(1-\epsilon_p)} P_{t-1}^{1-\epsilon_p}$. In this case, γ_p governs the degree of price indexation – the higher the γ_p is, the more weight on past inflation is given by firms. Thus, the aggregate prices evolve as a weighted sum of reset and lagged prices:

$$P_t^{1-\epsilon_p} = (1 - \phi_p)(P_t^*)^{1-\epsilon_p} + \phi_p \Pi_{t-1}^{\gamma_p(1-\epsilon_p)} P_{t-1}^{1-\epsilon_p} \tag{17}$$

In the benchmark calibration, $\phi_p = 0.82$ which implies that price contracts are reset every $1/(1 - 0.82) \sim 5.5$ quarters and $\gamma_p = 0.23$, both set to match the values from an estimated, large-scale DSGE model of the euro area – NAWM II (Coenen et al. (2018)). We then run two alternative simulations to pin down the role of price rigidities in the MP transmission. First, we recalibrate $\phi_p = 0.75$, a standard value in the literature, implying average duration of price contracts equal to 4 quarters. Second, we set $\gamma_p = 0.42$ as in Warne et al. (2008) – the original NAWM which was estimated using data prior to the Great Recession, with a spell of cost-push shocks often driving inflation above the target. Thus, this value for the indexation parameter is more reflective of the current pricing behaviour than the one used in the benchmark calibration.

Figure 10 illustrates the role of the degree of price stickiness in the pass-through of monetary policy. Simulations show that the repricing frequency is especially important and gives rise to a favourable trade-off for monetary policy stabilisation during the inflation surge as monetary tightening exerts a substantially higher impact on inflation with smaller output losses. Higher indexation to past inflation, while driving the IRFs in similar qualitative direction, affects the baseline estimates to a much lesser extent. Hence, a large shock-induced increase in price flexibility during the recent inflation surge laid the foundations for monetary policy to effectively stabilise inflation with a considerably smaller sacrifice ratio than historical regularities would imply. A forceful central bank response to this surge likely stabilised the repricing frequency as inflation expectations have remained broadly anchored in the post-pandemic era, as a result, preventing the incorporation of second-round effects into prices by firms[8]. However, it's also important to note that the repricing frequency largely normalised by the end of 2023, as illustrated in the Appendix H, implying that low sacrifice ratio is a temporary phenomenon and should not prevent the central bank from easing the contractionary policy stance once the inflationary pressures sufficiently subside.

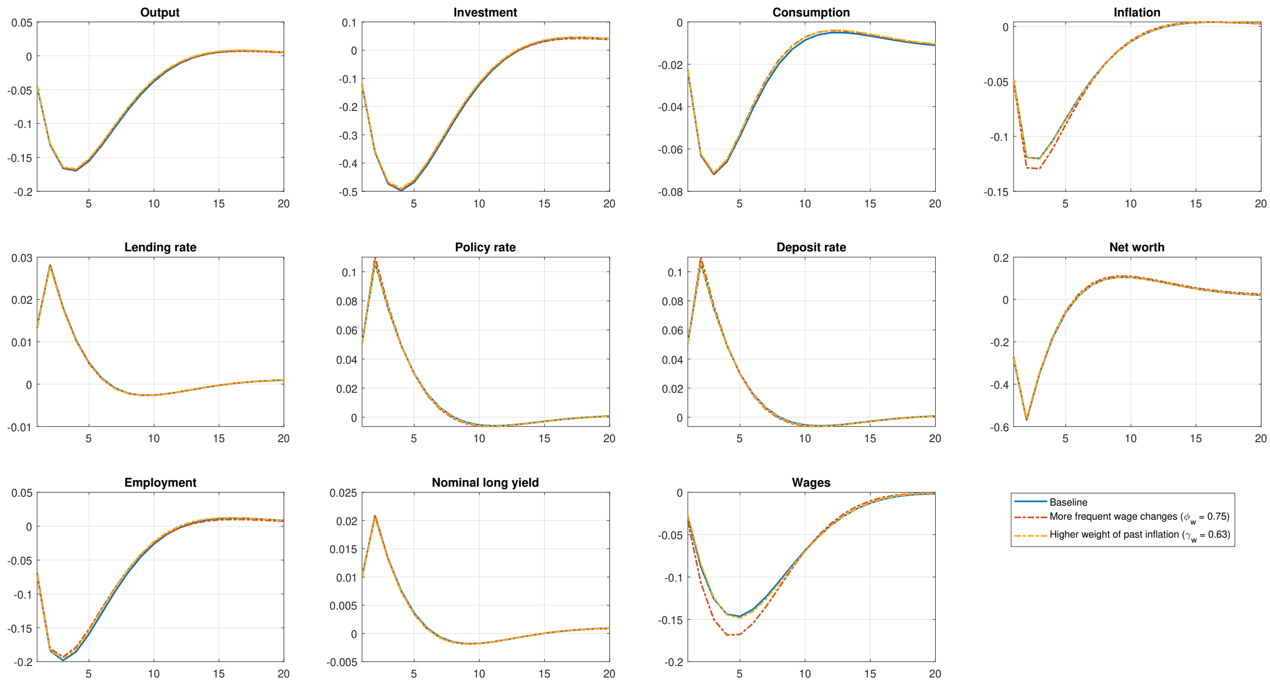
Another concern in the recent inflation surge has been attributed to a potential emergence of a wage-price spiral (see e.g. Lorenzoni and Werning (2023)), given the strength of the labour market. Strong wage growth has also often been mentioned in recent policy discussions as a risk for sustaining inflation higher-for-longer (see Cipollone (2024) among others).

Since wages in the model are set in a similar Calvo-like fashion, potential implications of more flexible wage-setting for monetary policy transmission can be determined by altering the parameters governing the duration of wage contracts and their indexation to inflation. In the baseline calibration, wage rigidity parameter $\phi_w = 0.78$, implying an average duration of wage contracts equal to ~ 4.5 quarters and wage indexation parameter $\gamma_w = 0.37$, both calibrated as in the NAWM II. We then create two counter-factual scenarios: recalibrate $\phi_w = 0.75$, a standard value in the literature, yielding an average duration of wage contracts equal to 4 quarters. Alternatively, we set $\gamma_W = 0.63$ as in Warne et al. (2008) to reflect a potentially larger weight of past inflation in wage indexation compared to the pre-pandemic period.

However, Figure 11 suggests that peculiarities related to wage-setting entail little implications for the effectiveness of monetary policy as both alternative scenarios generate almost identical IRFs to the benchmark. Only in the case when a slightly more frequent wage adjustment is assumed, the MP shock entails marginally higher disinflationary impact due to a more responsive wage reaction to the shock. While in the case when more active wage indexation to past inflation is assumed, the results are virtually identical to the baseline calibration. Nonetheless, we further explore the consequences of a tight labour market on the monetary transmission mechanism by investigating the role of real rigidities.

[8]Empirical evidence on greater impact of the ECB's monetary policy on inflation expectations in the euro area during the recent inflation surge will be provided in a spin-off paper "Monetary Policy Transmission in the Euro Area: Is this Time Different? Chapter II: Transmission Channels". Results are available upon request.

Figure 11: Exogenous conventional monetary policy shocks: the role of wage stickiness



Note: Figures show impulse response functions to the conventional monetary policy shock. Blue lines depict the benchmark responses. Red lines: simulation assuming more frequent wage adjustments, green lines: simulation with a higher degree of wage indexation.

In addition to swift wage developments, a post-pandemic labour market has also been characterized by a high degree of labour hoarding in light of persistent shortages, see evidence from Gayer et al. (2024) in Appendix I.

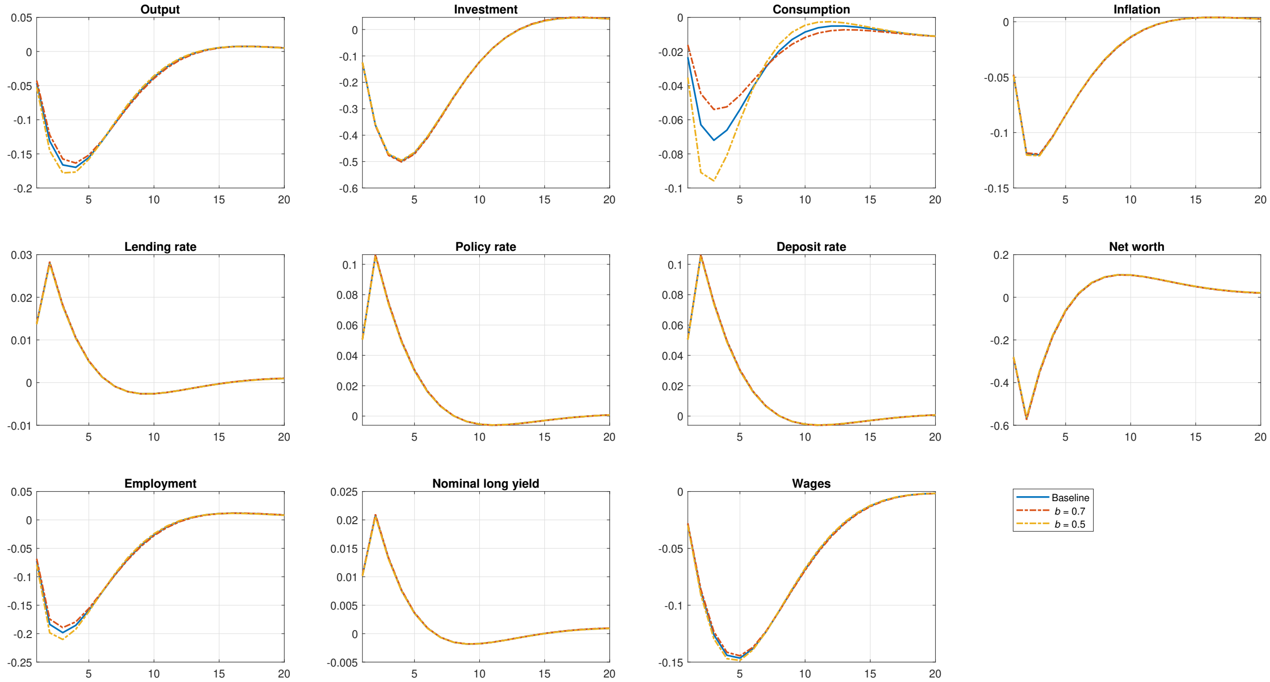
To rationalize the role of labour hoarding, we turn to two sources of real rigidities with respect to the household sector in our DSGE setup – habit formation in the consumption and disutility from supplying labour. Households in the model maximize an expected discounted lifetime utility in the form of:

$$\mathbb{E}_t \sum_{j=0}^{\infty} \beta^j \left\{ ln(C_{t+j} - bC_{t+j-1}) - \frac{\chi L_{t+j}^{1+\eta}}{1+\eta} \right\} \tag{18}$$

where b is a measure of internal habit formation and η is the inverse Frisch elasticity, governing the flexibility of labour supply. In the benchmark calibration, both parameters are set equal to NAWM II, i.e. $b = 0.62$ and $\eta = 2$.

Alternatively, we consider three simulations to assess the consequences of a potentially less flexible labour supply and ambiguity of consumption habits for the monetary policy transmission. Regarding habit persistence, a strong labour market could render household consumption less sensitive

Figure 12: Exogenous conventional monetary policy shocks: the role of habit persistence

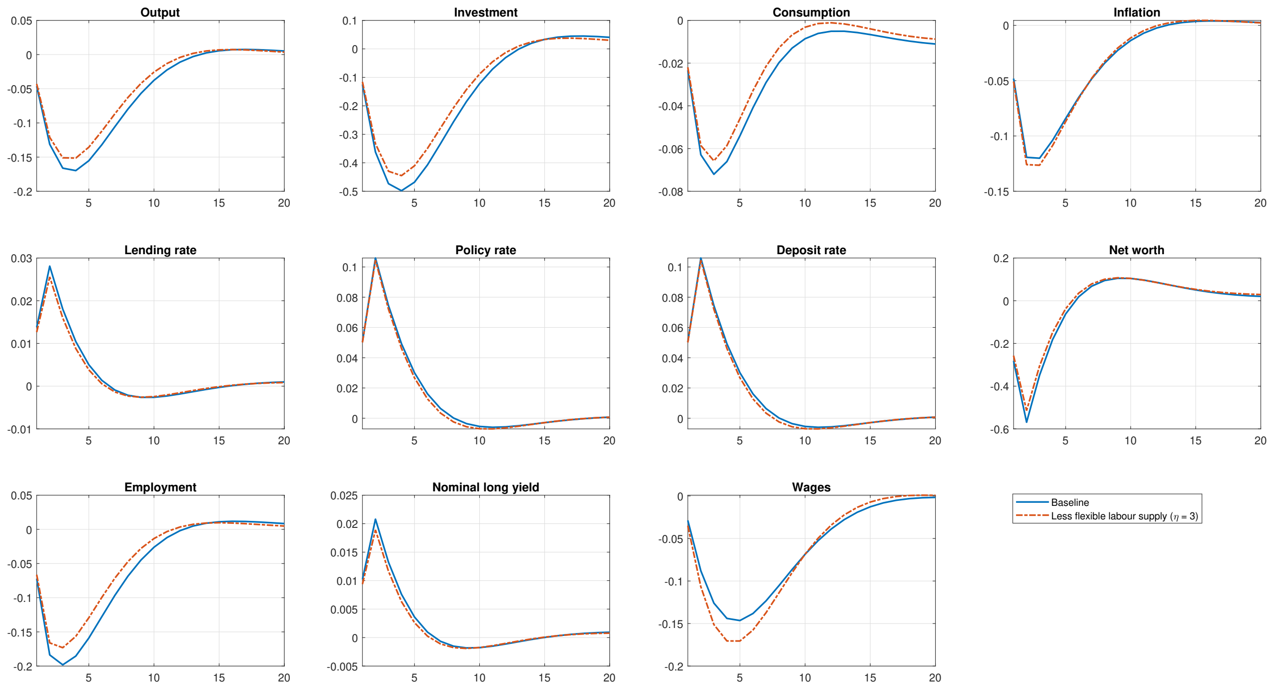


Note: Figures show impulse response functions to the conventional monetary policy shock. Blue lines depict the benchmark responses. Red lines: simulation assuming less responsive household consumption, green lines: simulation with more reactive household consumption.

to shocks, thus we calibrate habit persistence to a higher value than in the benchmark calibration, i.e. $b = 0.7$. On the other hand, the post-pandemic era has been characterized by significant uncertainty in light of large shocks hitting the economy, thus leading households to accumulate savings (see e.g. Battistini et al. (2023)). This could lead to a stronger drop in consumption; therefore we calibrate $b = 0.5$. As regards the flexibility of labour supply, we set inverse Frisch elasticity $\eta = 3$ to reflect a potentially weaker response of employment to monetary policy in the post-pandemic era.

Figure 12 and 13 illustrates the role of habit persistence and flexibility of labour in the transmission of exogenous monetary policy shock. Figure 12 shows that the habit persistence in consumption has a negligible impact on macroeconomic outcomes of monetary tightening since it only produces very slight differences in the response of output compared to the baseline estimates, with the effect on other variables being unchanged. On the contrary, Figure 13 indicates that a less flexible labour supply during a recent inflationary episode could have contributed to lowering the sacrifice ratio of monetary tightening. In particular, a weaker response of employment and more powerful response of wages generate smaller real effects while price pressures are stabilised more effectively. However,

Figure 13: Exogenous conventional monetary policy shocks: the role of labour supply flexibility



Note: Figures show impulse response functions to the conventional monetary policy shock. Blue lines depict the benchmark responses. Red lines: simulation assuming a less flexible labour supply.

the differences between both scenarios are relatively mild, thus leading us to conclude that labour hoarding has had limited implications for the recent monetary tightening.

7 Conclusions

This paper provides a comprehensive investigation of how the ECB's conventional monetary policy have propagated to the euro area over two decades of its existence, with a particular focus on the recent tightening episode. To that end, we have employed a set of empirical frameworks, namely a linear SVAR as well as a SVAR featuring time-variation both in the parameter space and shock volatilities to trace potential changes in the monetary transmission mechanism. In addition, we deploy a medium-scale New Keynesian DSGE setup to rationalize our empirical findings and identify the key factors affecting the stabilisation properties of monetary policy in the post-pandemic environment.

Our findings suggest it takes approximately 12 – 18 months for a conventional monetary policy shock to reach its peak impact on key variables of interest – Real GDP and headline inflation. This result is robust to a wide array of stability tests: frequency of time series used in the estimation of models (monthly/quarterly), identification strategy of monetary policy shock (Cholesky decomposition/sign and zero restrictions/multiple HFI shocks), alternative estimator of impulse response functions (local projections), and when controls for omitted variable bias are introduced in the model. However, we also document that the transmission lags to more persistent HICP items – core and services inflation – are substantially longer as a full pass-through requires more than two years to materialize. A recent surge in inflation has been characterized by strong and very persistent price pressures in the services sector, causing a serious concern among the policymakers regarding the threat of sticky services inflation to medium-term price stability. Therefore our evidence suggests that the bulk of the impact from monetary tightening of 2022 and 2023 is still in the pipeline and will contribute to the softening of services prices in the coming years, minimizing the risks of sticky services inflation to medium-term price stability. Furthermore, our non-linear estimates reveal that the transmission of recent policy rate hikes to headline and core/services has been considerably stronger than in the past tightening cycles. A salient feature of this tightening cycle has been an exceptionally low sacrifice ratio of monetary policy as the impact on output has been broadly in line with historical regularities.

Simulations via a medium-scale DSGE framework point out two ingredients which have contributed to the stabilisation properties of monetary policy in the recent tightening cycle. First, a post-pandemic inflation surge has been marked by a substantial increase in the repricing frequency, implying an upward shift in the slope of the Phillips curve. *Ceteris paribus*, the steeper the Phillips curve, the lower the sacrifice ratio of monetary policy stabilisation, since more flexible price-setting lessens the level of nominal rigidity in the economy and thus dampens the real effects of monetary policy. Second, a forceful and persistent monetary policy response to the inflation surge contained an up-side deanchoring of inflation expectations, preventing the incorporation of second-round effects into prices by firms. Model simulations also illustrate that a more flexible wage-setting due to tight conditions in the post-pandemic labour market and associated labour hoarding has limited repercussions for monetary policy effectiveness. We leave further analysis on the strength of specific transmission channels for future research.

To sum up, this paper contributes to the literature on the transmission of the ECB's conventional monetary policy to the euro area, with a special focus on the recent tightening cycle. The main lesson provided by this inflationary episode is that in response to large supply-side related shocks, central banks shouldn't attempt to "look through" those disturbances as conventional wisdom would suggest. Instead, such inflation surges require a forceful and persistent monetary policy response to stabilise the frequency of upward changes in firms' price-setting. Moreover, central banks shouldn't fear large output losses as an increase in the slope of the Phillips curve gives rise to a favourable trade-off for monetary policy stabilisation in such circumstances.

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A Dataset description

In this appendix, we describe the data used in the estimation of linear SVAR and TVP-SVAR-SV models.

1. Real GDP – real gross domestic product, chain linked volumes index, 2015=100, working day and seasonally adjusted data. Monthly series are obtained by performing the Litterman temporal disaggregation procedure using the industrial production index as an indicator series, from Eurostat.

2. HICP inflation – Y-o-Y change in all-items HICP, 2015=100, working day and seasonally adjusted data, from ECB.

3. 3-month EURIBOR – money market interest rate, from Eurostat.

4. Euro Stoxx 50 – Dow Jones Euro Stoxx 50 stock price index, from ECB.

5. EUR/USD – monthly average value of the euro per US dollar, from Eurostat.

6. Unemployment – percentage of unemployed population in the labour force, seasonally adjusted data, from Eurostat.

7. Economic sentiment – Economic Sentiment Indicator, seasonally adjusted data, from the European Commission.

8. Core HICP inflation – Y-o-Y change in all-items HICP excluding energy and food, 2015=100, working day and seasonally adjusted data, from ECB.

9. HICP services inflation – Y-o-Y change in all-items HICP excluding goods, 2015=100, working day and seasonally adjusted data, from ECB.

10. Lending to non-MFIs – Loans vis-a-vis euro area Non-MFIs excl. general gov. reported by MFIs excl. ESCB, from ECB.

11. NFC deposits – deposit liabilities vis-a-vis euro area NFCs reported by MFIs excl. ESCB, from ECB.

12. HH deposits – deposit liabilities vis-a-vis euro area households reported by MFIs excl. ESCB, from ECB.
13. NFC deposit rate – rate for deposits from corporations with an agreed maturity (new business), from ECB.
14. HH deposit rate – rate for deposits from households with an agreed maturity (new business), from ECB.
15. CISS – Composite Indicator of Systemic Stress, from ECB.
16. PCCI – Persistent and Common Component of Inflation (overall), from ECB.
17. PCCI excluding energy – Persistent and Common Component of Inflation (excluding energy), from ECB.
18. NEIG inflation – Y-o-Y change in all-items HICP, 2015=100, working day and seasonally adjusted data, from ECB.
19. EONIA/€STR – money market interest rate. Data for the EONIA from 2022 onwards is extrapolated from the monthly difference in the €STR, from Eurostat and ECB.
20. 1-month EURIBOR – money market interest rate, from Eurostat.
21. 1-month OIS – overnight index swap interest rate, from Bloomberg.
22. 1-year DE bond yield – German government bond yield, from Bloomberg.
23. Brent oil price – Brent spot price FOB (US dollars per barrel), from US Energy Information Administration.
24. Employment – Total employment, domestic concept, working day and seasonally adjusted data, from Eurostat.

B Identification via HFI + Narrative Sign Restrictions

The identification of conventional and unconventional monetary policy shocks in the euro area largely follows the approach of Zlobins (2022) and Grüning and Zlobins (2023) which further extends it in order to accommodate the identification of a market-stabilisation QE (MS-QE) shock in the spirit of Motto and Özen (2022). In essence, this methods augments the high frequency identification approach with narrative sign restrictions of Antolín-Díaz and Rubio-Ramírez (2018) to sharpen the inference and capture multiple monetary policy shocks in policy announcements.

In the first step, we gather high frequency reactions of the risk-free yield curve and stock prices around the ECB policy announcements from the Euro Area Monetary Policy Event-Study Database (EA-MPD) of Altavilla et al. (2019). We use the press release window surprises for conventional policy shocks and press conference window reactions for all unconventional policy innovations. Then we include high frequency surprises in the VAR and ensure that they do not depend on their own lags:

$$m_t = a_0 + \sum_{j=1}^{p} 0 \, m_{t-j} + \epsilon_t, \tag{B.1}$$

where m_t are the high frequency reactions of the 3-month, 1-year, and 10-year OIS rates, the 10-year Italian bond yield and the Euro Stoxx 50 stock price index to ECB policy announcements (both in the press release and press conference windows). Our choice of these particular OIS maturities is motivated by the evidence from Altavilla et al. (2019) and Rostagno et al. (2021) showing that each instrument targets a specific region of the yield curve. For instance, QE predominantly loads on the back-end of the term structure, while forward guidance (FG) loads on medium-term maturities. Regarding the negative interest rate policy (NIRP), we assume that it has the largest impact on short-term rates, similar to conventional policy. However, instead of the press release, it primarily operates in the press conference window, given the resemblance to an FG-type shock. The 10-year Italian yield is included to capture the effects of market-stabilisation QE instruments, aimed to minimise the fragmentation risk in the euro area sovereign bond markets, such as the Outright Monetary Transactions (OMT), Securities Market Programme (SMP), one dimension of the Pandemic Emergency Purchase Programme (PEPP), and the recently announced Transmission Protection Instrument (TPI). The VAR is estimated monthly from January 2002 to October 2023 with standard Bayesian techniques by specifying an independent Normal-Wishart prior.[9]

[9] We set the AR coefficient of the prior to 0, overall tightness to λ_1=0.1, cross-variable weighting to $\lambda_2 = 0.5$, the

In the second step, we apply a set of traditional sign restrictions, summarised in Table B.1. All restrictions are imposed to hold on impact only. The identification of the market-stabilisation QE shock largely follows Motto and Özen (2022) who show that this type of shock moves periphery-country yields in opposite direction to risk-free and core-country yields. In addition to the identification of conventional and unconventional monetary policy disturbances, we also control for the effects of information shocks following the logic put forth in Jarociński and Karadi (2020) by assuming that the release of central bank information during policy announcements entails a positive co-movement between interest rates and stock prices.

Table B.1: Set of traditional sign restrictions used to distinguish monetary policy instruments

Shock	3-month OIS (press release)	3-month OIS (press conference)	1-year OIS	10-year OIS	10-year IT	Euro Stoxx 50
CMP	−					+
NIRP		−				+
FG			−			+
QE				−	−	+
MS-QE				+	−	+
Information		−	−	−		−

Notes: This table summarises the traditional sign restrictions used for the identification of monetary policy disturbances.

However, given that policy shocks of an Odyssean nature induced by different monetary policy tools move surprises in the same direction, pure sign restrictions alone are insufficient to clearly distinguish the effects of multiple monetary policy instruments. Mechanical orthogonalisation via zero restrictions, on the other hand, would be too restrictive as the ECB has often announced and/or recalibrated several instruments in its toolkit during the same meeting of the Governing Council. Hence, we augment traditional sign restrictions with narrative information about the respective shocks, using the approach of Antolín-Díaz and Rubio-Ramírez (2018), which allows for implementing narrative information by placing restrictions on the structural disturbances and historical decompositions in addition to sign restrictions on the impulse response functions and structural parameters, sharpening the inference. In particular, we supplement our identification strategy with the following narrative information to distinguish between the effects of different monetary policy measures:

- **Narrative Sign Restriction I.** *An expansionary conventional monetary policy (CMP) shock took place in November 2011.*

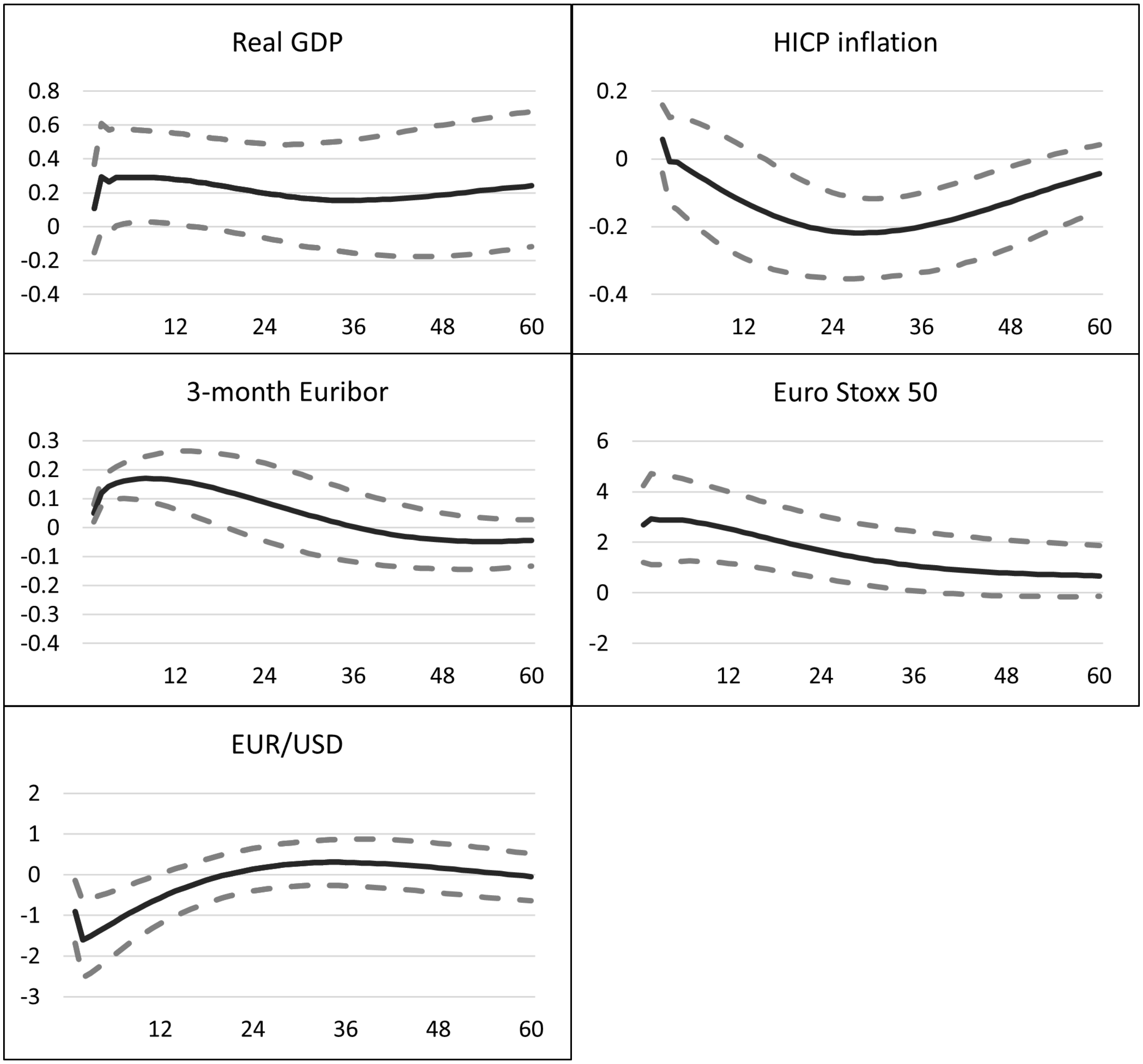
lag decay to $\lambda_3 = 1$, and block exogeneity shrinkage to λ_5=0.001.

- **Narrative Sign Restriction II.** *For November 2011, the CMP shock was the overwhelming driver of the unexpected movement in the 3-month OIS (press release window).*
- **Narrative Sign Restriction III.** *An expansionary NIRP shock took place in June 2014.*
- **Narrative Sign Restriction IV.** *For June 2014, the NIRP shock was the overwhelming driver of the unexpected movement in the 3-month OIS (press conference window).*
- **Narrative Sign Restriction V.** *An expansionary FG shock took place in July 2013.*
- **Narrative Sign Restriction VI.** *For July 2013, the FG shock was the overwhelming driver of the unexpected movement in the 1-year OIS.*
- **Narrative Sign Restriction VII.** *An expansionary QE shock took place in January 2015.*
- **Narrative Sign Restriction VIII.** *For January 2015, the QE shock was the overwhelming driver of the unexpected movement in the 10-year OIS.*
- **Narrative Sign Restriction IX.** *An expansionary market-stabilisation QE shock took place in September 2012.*
- **Narrative Sign Restriction X.** *For September 2012, the market-stabilisation QE shock was the overwhelming driver of the unexpected movement in the 10-year Italian yield.*

To sum up, for each of the five monetary policy shocks we identify, we restrict both the sign of the structural disturbance as well as the historical decomposition of the corresponding maturity surprise on which the respective instrument primarily loads. For the NIRP, FG, and QE shocks, the choice of dates is straightforward as the selected Governing Council meetings are the ones in which the respective instruments were first officially announced. For the MS-QE, however, the date is motivated by the evidence in Motto and Özen (2022) who show that the largest expansionary realisation of the shock took place in September 2012 when the ECB announced the details of the OMT programme. Finally, our choice of the specific date for the CMP shock is motivated by the largest recorded easing surprise in the 3-month OIS rate (in the press release window) in the considered sample period as well as the fact that this conventional policy action was the last one before the ECB switched to a mix of unconventional policy tools, aiding the identification.

C Using the MP shock of Jarociński and Karadi (2020) in a baseline model

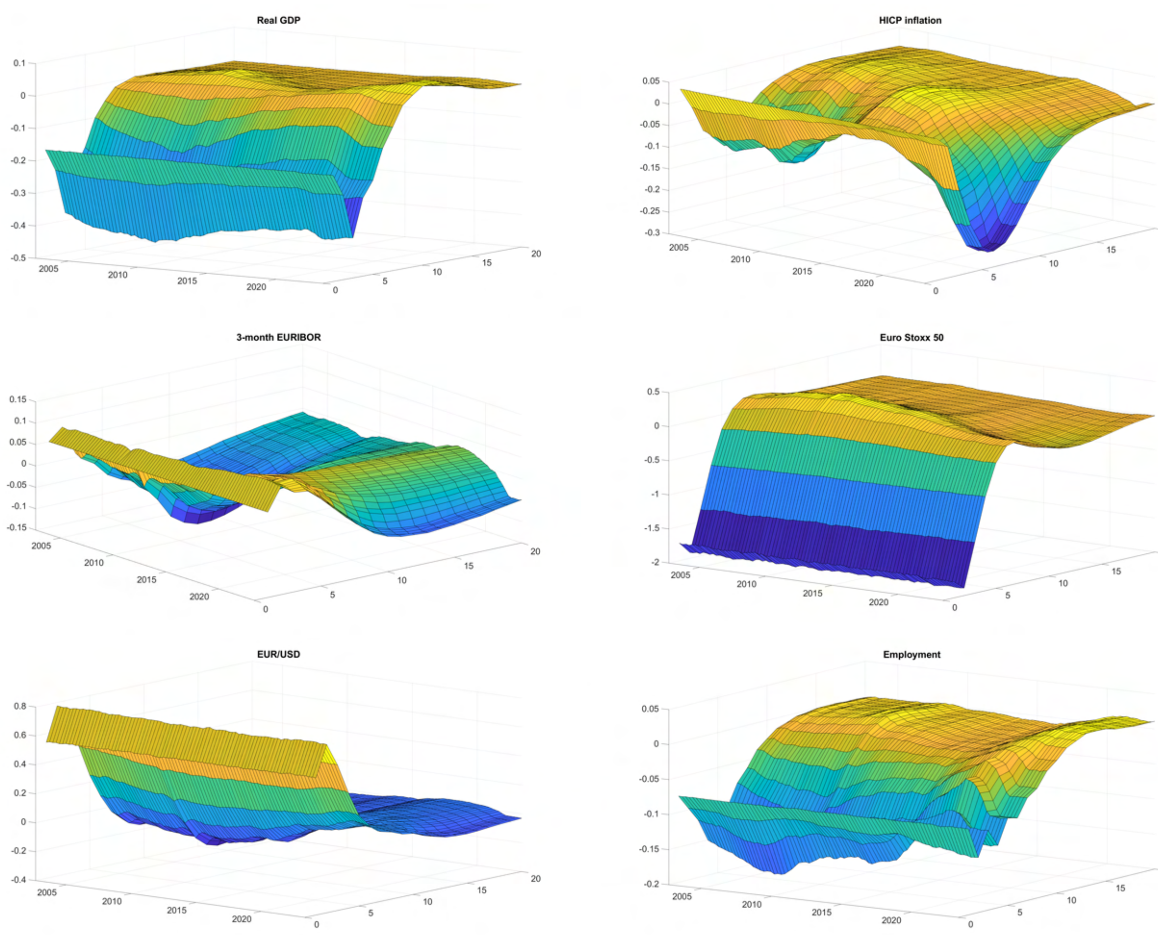
In this appendix, we show the IRFs when the MP shock of Jarociński and Karadi (2020) is used in the benchmark model with the 3-month EURIBOR as a proxy for the policy rate.



Note: Figures show impulse response functions from a Bayesian SVAR to the MP shock of Jarociński and Karadi (2020), normalized to generate a 5 bps increase in the 3-month EURIBOR. The solid line shows the median response while the dashed region denotes the 68% credible sets.

D Response of employment over time

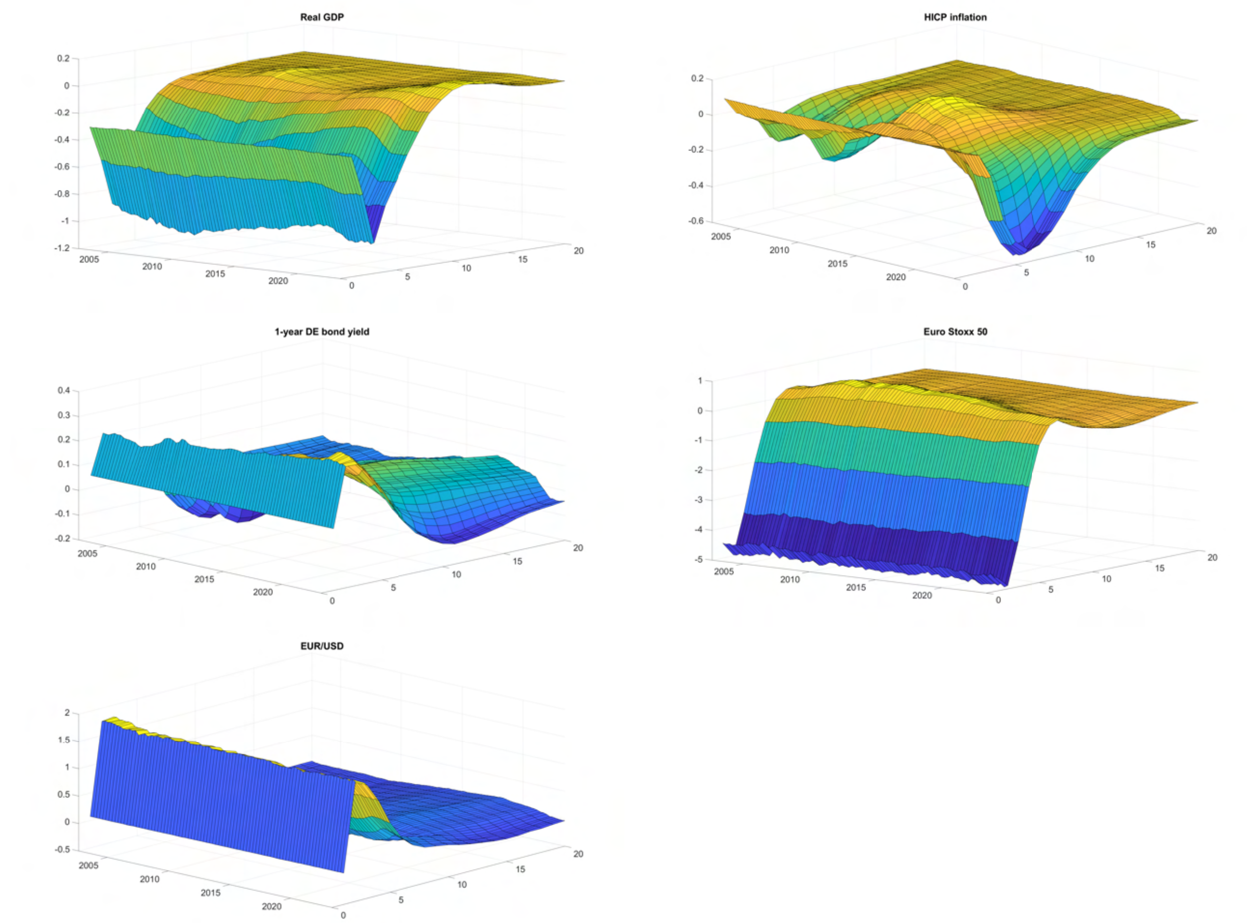
This appendix provides the results regarding the impact of monetary policy on employment over time.



Note: Figures show impulse response functions from the TVP-SVAR-SV to the CMP shock over the period from Q3 2002 to Q3 2023. The shock has been normalized to a 5 bp increase in the 3-month EURIBOR in each period, allowing the estimated elasticities to be comparable over time. All variables are expressed as Y-o-Y growth rates except the 3-month EURIBOR, which enters the model in levels.

E Using the MP shock of Jarociński and Karadi (2020) in a TVP-SVAR-SV

This appendix contains a robustness check of estimates from the TVP-SVAR-SV by considering the MP shock of Jarociński and Karadi (2020)[10] instead of the CMP shock, obtained via the fusion of high frequency information with narrative sign restrictions.



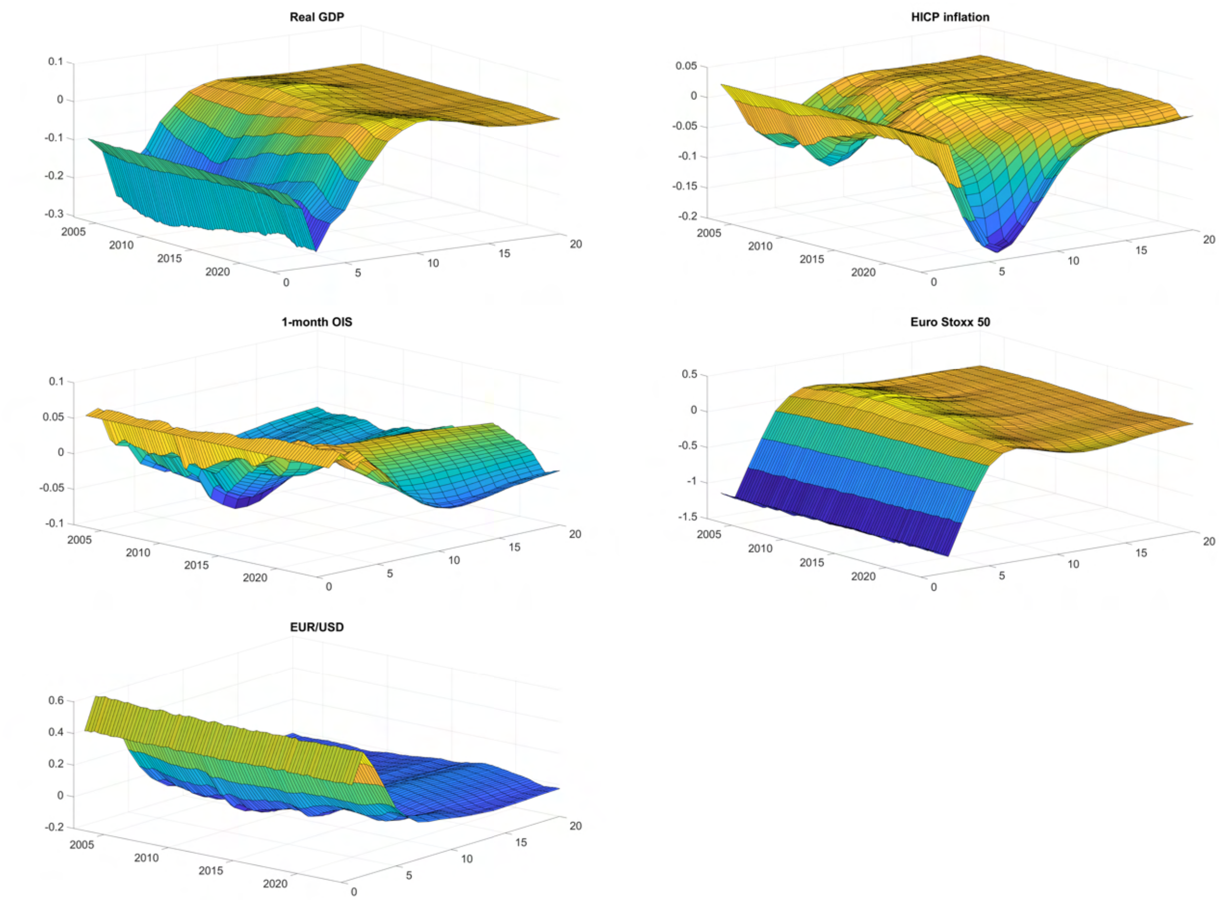
Note: Figures show impulse response functions from the TVP-SVAR-SV to the MP shock of Jarociński and Karadi (2020) over the period from Q3 2002 to Q3 2023. The shock has been normalized to a 5 bp increase in the 1-year DE government bond yield in each period, allowing the estimated elasticities to be comparable over time. All variables are expressed as Y-o-Y growth rates except the 1-year DE government bond yield, which enters the model in levels.

[10]We use the MP shock obtained with the median rotation approach that implements the sign restrictions algorithm.

F Using alternative proxies for the policy rate in a TVP-SVAR-SV

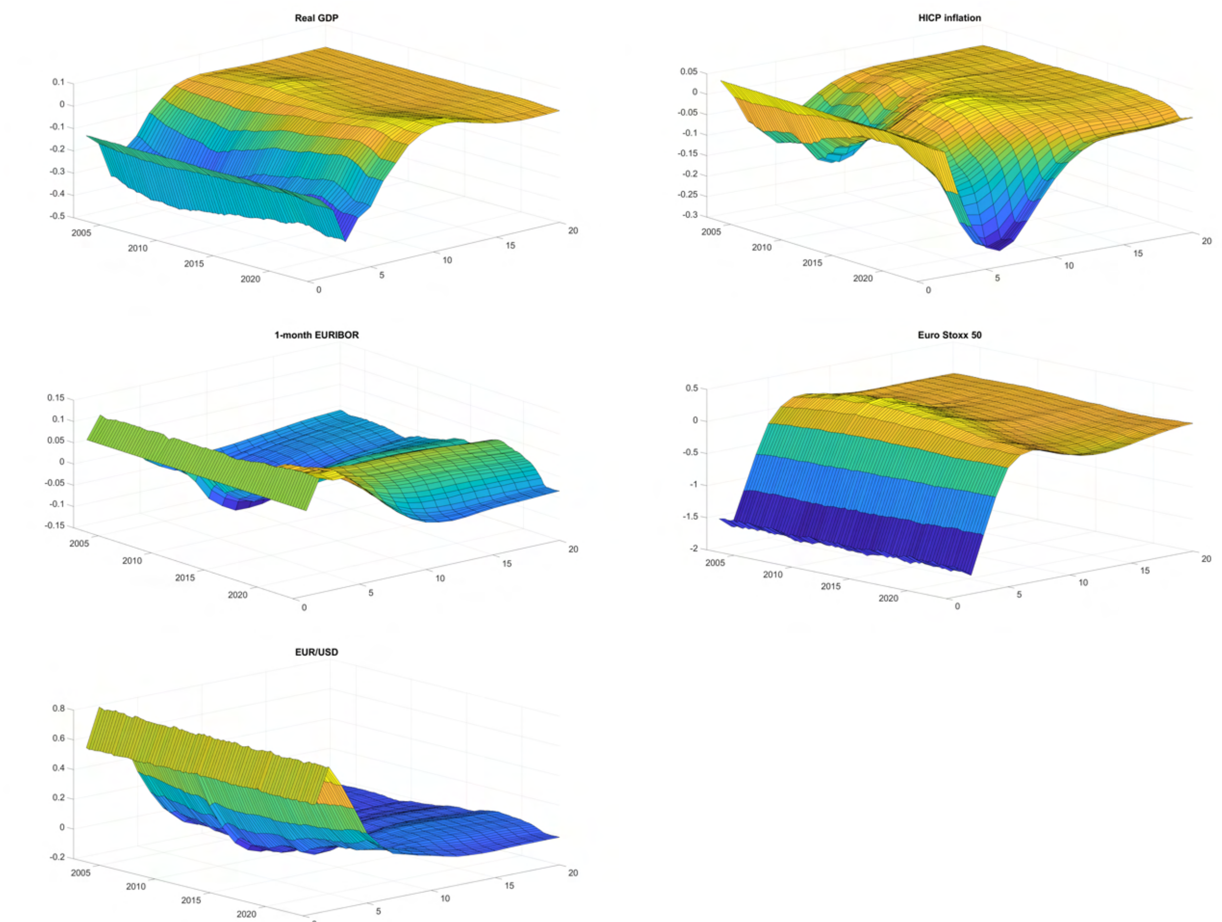
In this appendix, we check the sensitivity of estimates with respect to the choice of proxy for the policy rate. Specifically, we show that the results remain robust when a 1-month OIS, 1-month EURIBOR or the EONIA/€STR is employed instead of a 3-month EURIBOR.

Figure F.1: 1-month OIS



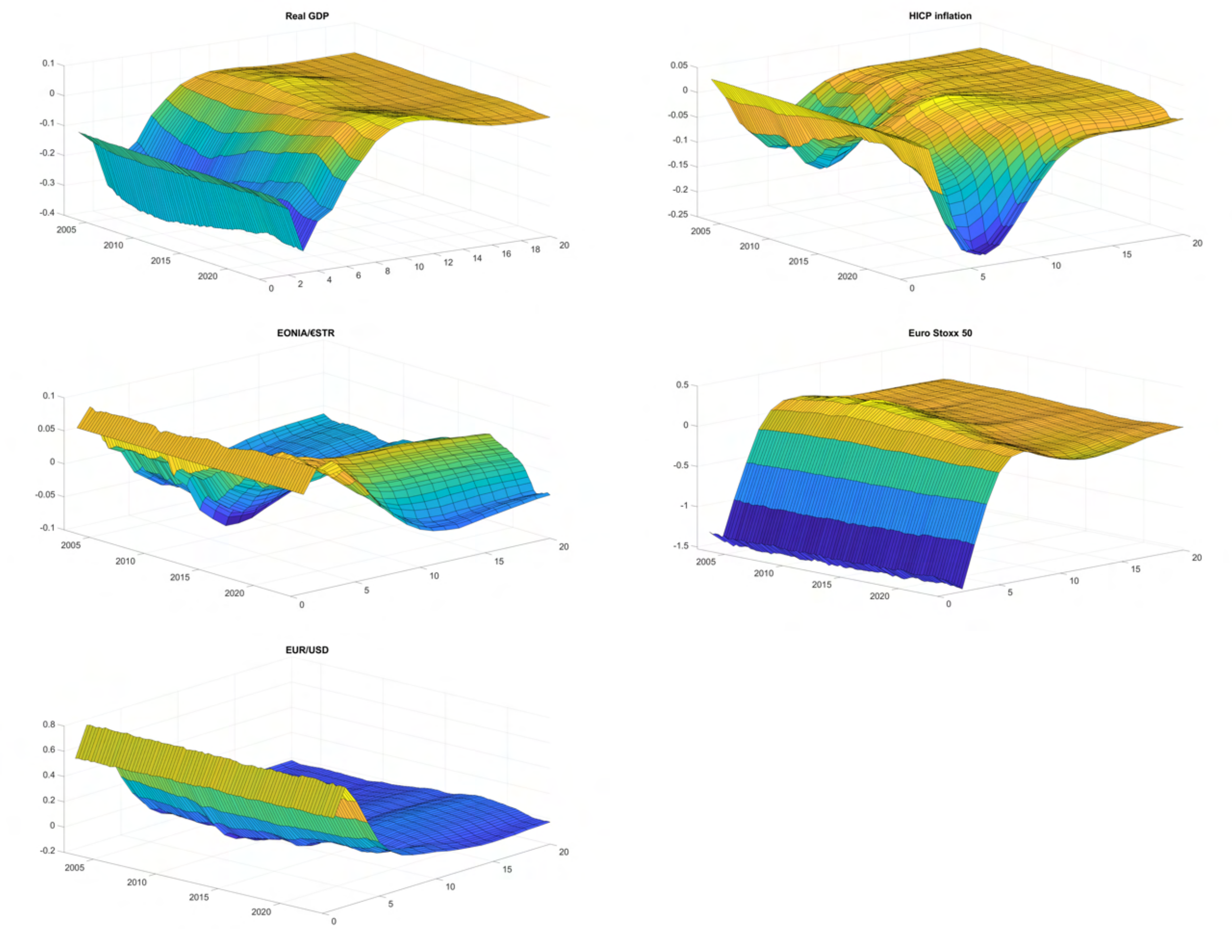
Note: Figures show impulse response functions from the TVP-SVAR-SV to the CMP shock over the period from Q3 2002 to Q3 2023. The shock has been normalized to a 5 bp increase in the 1-month OIS in each period, allowing the estimated elasticities to be comparable over time. All variables are expressed as Y-o-Y growth rates except the 1-month OIS, which enters the model in levels.

Figure F.2: 1-month EURIBOR



Note: Figures show impulse response functions from the TVP-SVAR-SV to the CMP shock over the period from Q3 2002 to Q3 2023. The shock has been normalized to a 5 bp increase in the 1-month EURIBOR in each period, allowing the estimated elasticities to be comparable over time. All variables are expressed as Y-o-Y growth rates except the 1-month EURIBOR, which enters the model in levels.

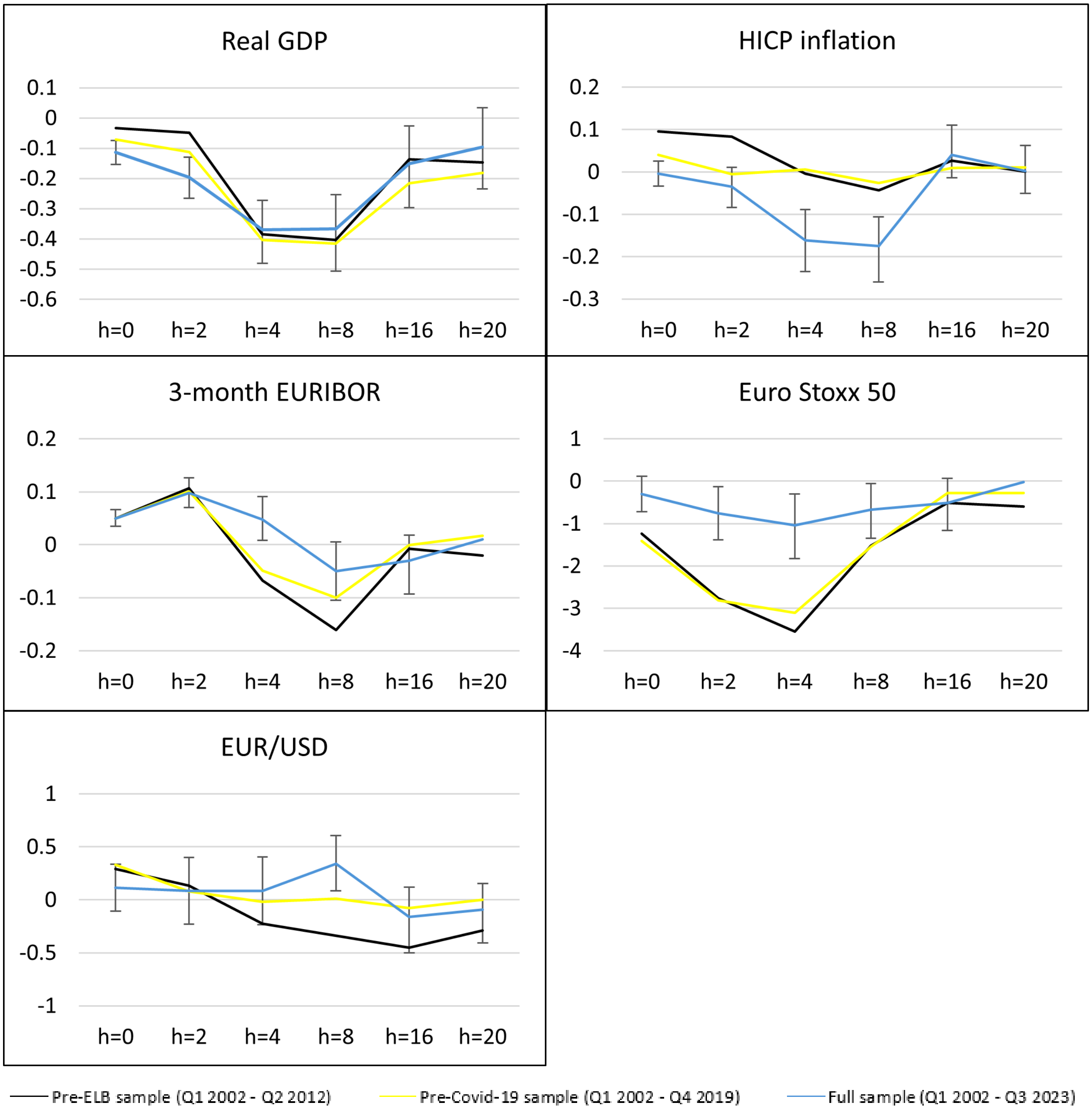
Figure F.3: EONIA/€STR



Note: Figures show impulse response functions from the TVP-SVAR-SV to the CMP shock over the period from Q3 2002 to Q3 2023. The shock has been normalized to a 5 bp increase in the EONIA/€STR in each period, allowing the estimated elasticities to be comparable over time. All variables are expressed as Y-o-Y growth rates except the EONIA/€STR, which enters the model in levels.

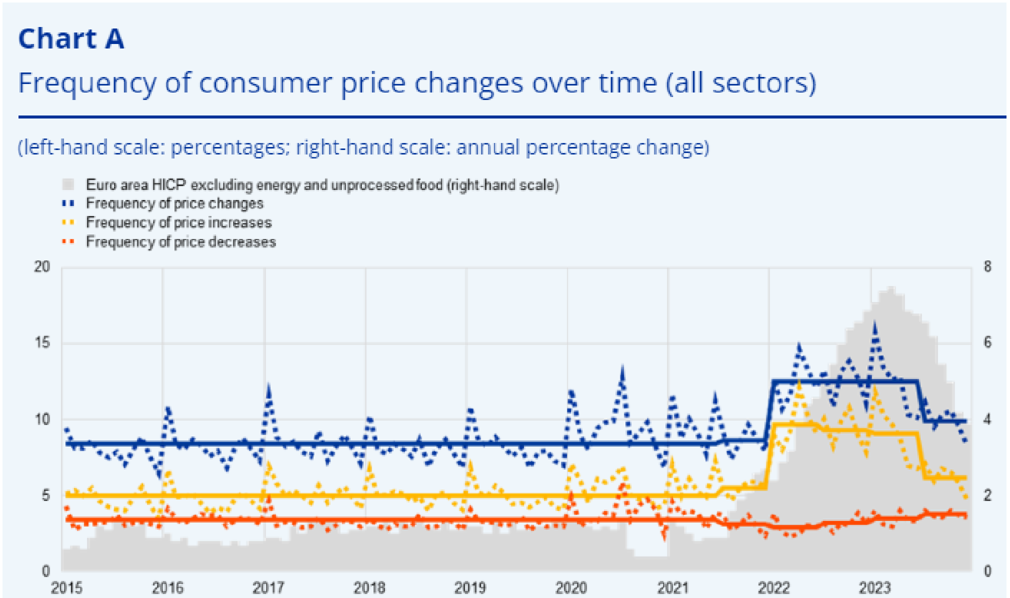
G Sub-sample analysis with linear SVAR

In this Appendix, we cross-check our non-linear estimates, obtained via the TVP-SVAR-SV, with a linear Bayesian SVAR, estimated with quarterly data over various sub-samples.



Note: Figures show impulse response functions from a Bayesian SVAR to the CMP shock, normalized to generate a 5 bps increase in the 3-month EURIBOR. Solid lines show the median responses at selected horizons while whiskers denote the 68% credible sets from estimation using the full sample.

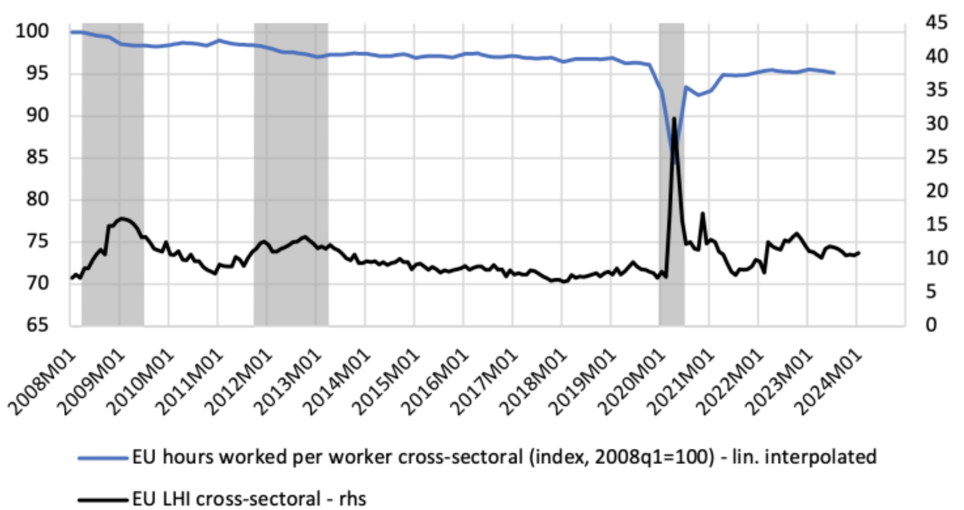
H Price adjustment patterns during the inflation surge in the euro area



Source: Dedola et al. (2024)

I Labour hoarding in the euro area

Figure 2 EU (cross-sectoral) LHI and hours worked per worker



Notes: The shaded areas reported in the graph represent technical recessions corresponding to at least two quarters of negative (quarter-on-quarter) GDP growth. The Eurostat national accounts dataset contains information on total employment and total hours worked. Hours worked per worker are obtained by dividing total hours worked by total employment.
Data Sources: Eurostat, Directorate-General for Economic and Financial Affairs of the European Commission.

Source: Gayer et al. (2024)