Finance and Economics Discussion Series

Federal Reserve Board, Washington, D.C.
ISSN 1936-2854 (Print)
ISSN 2767-3898 (Online)

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2025-087

Please cite this paper as:
González-Astudillo, Manuel, and Diego Vilán (2025). "One Policy Rate, Many Stances: Evidence from the European Monetary Union," Finance and Economics Discussion Series 2025-087. Washington: Board of Governors of the Federal Reserve System, https://doi.org/10.17016/FEDS.2025.087.

One Policy Rate, Many Stances: Evidence from the European Monetary Union

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September 1, 2025

Abstract

A challenge for conducting monetary policy in a currency union is the diverse economic conditions among member states. Such disparities can drive natural interest rates apart, thereby undermining the stabilizing role of a unified monetary policy. To assess the stance of monetary policy across Eurozone-19 countries, we estimate their natural rates of interest (r^*) and inflation trends (π^*) to construct a measure of the country-level neutral nominal interest rates ($r^* + \pi^*$) over 1999-2025, using a semi-structural model that jointly characterizes the trend and cyclical components of key macroeconomic variables such as output, unemployment, inflation, 10-year government bond yields, and the common policy interest rate. Our setup improves upon those in the existing literature by allowing both a short-run interest rate gap—driven by the (shadow) policy rate—and a long-run interest rate gap—driven by the country-specific 10-year government bond yields—to affect and reflect economic conditions. We also impose cointegration between the dynamics of the country-specific latent variables and common counterparts to incorporate co-movements across the euro area economies. Our results show that the stance of monetary policy is homogeneous across the countries in our sample, but that a relatively highly degree of heterogeneity emerges at key historical turning points.

Keywords: Common monetary policy challenges, Euro area economies, Interest rate gap, Neutral interest rate, Sovereign debt risk.

JEL Classification Numbers: C32, E32, E42, E52.

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[*]The views expressed in this paper are solely the responsibility of the authors and should not be interpreted as reflecting the views of the Board of Governors of the Federal Reserve System. Manuel González-Astudillo is a member of the graduate faculty at ESPOL.

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1 Introduction

In a currency union, monetary policy is centrally managed by a single monetary authority, such as the European Central Bank (ECB) in the Eurozone, whose primary mandate is to set monetary policy to maintain price stability for the union as a whole.[1]. However, successfully implementing monetary policy in such a context can be especially challenging. For instance, the monetary authority may set interest rates based on aggregate economic indicators that may not be consistent with the needs of individual countries due to the divergence in economic conditions among member states and their inability to adjust national exchange rates. As a result, some member states may find monetary policy either too restrictive or too accommodative, potentially leading to imbalances in inflation, output growth, and employment. Moreover, the effectiveness of a common policy instrument could also be further hindered by asymmetric shocks (e.g. demographic or about fiscal sustainability) or structures (e.g. functioning of financial markets or industry composition).

This paper assesses the monetary policy stances in 19 euro area countries over the period 1999-2025, considering the implications of a single ECB monetary policy for economies with diverse economic conditions. To achieve that goal, we estimate the level of the neutral nominal interest rate for each country—defined as the sum of the natural interest rate (r^*) and trend inflation (π^*)—and contrast it with the ECB's main refinancing operations interest rate (the policy rate hereafter). If the policy rate is above the neutral nominal interest rate of a particular country, the monetary policy stance is deemed to be restrictive for that country, and vice versa.

Despite having a symmetric 2 percent euro-wide inflation target, and even if inflation expectations were well anchored at that level across euro area members, differences in the

[1]The ECB, in its 2025 monetary policy strategy assessment, defines price stability as a symmetric 2 percent inflation target over the medium term, measured by the change in the Harmonised Index of Consumer Prices (HICP) for the euro area. While temporary deviations are tolerated in light of economic shocks and transmission lags, the ECB commits to responding with sufficient force or persistence whenever inflation remains away from the 2 percent objective for an extended period, in order to restore price stability and maintain well-anchored long-term inflation expectations.

magnitudes of r^* would mean differences in the levels of the neutral nominal interest rate across countries and, hence, in the monetary policy stance prevalent in each country. These differences in r^* can arise from disparities in its determinants across countries, such as productivity growth, demographics, fiscal policy, uncertainty, income and wealth inequality, financial frictions, to name a few. Indeed, research indicates that estimates of r^* differ notably among euro area countries (see Brand, Bielecki and Penalver, 2018; Fries et al., 2018, for example), which could complicate the efficacious implementation of a single monetary policy.

To achieve our goal, we postulate and estimate a semi-structural model for each country of the Eurozone that allows us to infer country-specific r^* and π^* that form our measures of the neutral nominal interest rate. This is the rate against which the ECB policy rate is contrasted to determine the country-specific monetary policy stances. Our model builds upon past research that has established a framework to jointly and consistently estimate macroeconomic "stars" such as potential output (and the associated output gap) and the natural unemployment rate in addition to r^* and π^* (see González-Astudillo and Laforte, 2025; Zaman, 2025, for applications to the U.S. economy).

However, our setup is improved with respect to the previous literature and is attuned to the economies of the euro area. First, our IS curve equation involves two interest rate gaps, one in the spirit of the seminal work of Laubach and Williams (2003) for the short-term interest rate and another in terms of the long-term interest rate, as in González-Astudillo and Laforte (2025). This approach seeks to capture the multifaceted nature of a country's monetary policy stance by incorporating information from multiple yield maturities.

The short-term interest rate gap is computed from an uncensored policy rate that allows us to incorporate at least partially the effects of the unconventional monetary policy carried out by the ECB. Both forward guidance and long-term asset purchase programs are reflected in the union's shadow rate and transmitted across the yield curve. González-Astudillo and Laforte (2025) show that working with a policy rate specification that ignores censoring can distort the estimate of r^* and produce an inferior forecasting performance of the model when compared with one that takes censoring into account. Moreover, the long-term interest rate gap we introduce in our IS equation is aimed at incorporating the effects of sovereign debt risk and other country premiums. Bucacos (2020) and Zarazúa Juárez (2023) argue that sovereign debt risk premiums can affect the estimate of r^*, which means that ignoring a variable that proxies for these premiums for countries that went through the European debt crisis could produce biased results. In a similar vein, Del Negro et al. (2019) highlights the importance of accounting for the premium that international investors are willing to pay to hold safe and liquid assets when estimating trends in real interest rates.

Second, we assume a single policy rate across countries in our sample, consistent with the features of the euro area, and model its evolution using an inertial Taylor rule that takes a weighted average of the country-level variables, such as the output gap, as its inputs. Moreover, we introduce a censoring treatment that allows us to estimate an euro area shadow rate whenever the ECB policy rate is constrained by the zero lower bound (ZLB). This is the rate against which the country-specific neutral rates are contrasted to assess the monetary policy stance of each member state. We also assume that the inflation expectations variable informing our estimate of π_t^*, the euro-area inflation trend, is an unbiased estimator of euro-wide longer-run consumer inflation expectations.

Third, our setup includes common star variables in addition to country-specific ones. The latter depend on the common latent variables through country-specific loading coefficients in addition to country-specific components. Moreover, we impose cointegration between the country-specific and common stars to incorporate co-movements in the dynamics of macroeconomic variables among euro area economies.

We find strong evidence of a largely uniform monetary policy stance across the Euro-19 countries for most of the sample period, with interest rate gaps ranging between approximately negative three and four percent. However, cross-country divergences emerged around two episodes: the aftermath of the European sovereign debt crisis and the COVID-19 pandemic recession, including its immediate aftermath. In the first episode, our estimates of sovereign spreads widened sharply, particularly in Greece, Ireland, and Portugal, leading to significantly tight overall financial conditions, while other economies, such as Germany, Austria, and the Netherlands, experienced risk premiums well below average that reflected their safe-haven status. This divergence in country risk premiums likely affected the uniform transmission of monetary policy across the Eurozone. During the pandemic episode, even though we do not estimate country risk premiums to have widen or diverged across the euro area significantly, the monetary policy stance for many non-core economies was relatively less accommodative than the rest, with some countries—most notably Lithuania, Slovakia, and Slovenia—even experiencing restrictive conditions during this period.

We also examine the transmission mechanism of the model's single monetary policy by analyzing the propagation of a one–percentage point increase in the policy rate sustained for four quarters. Our results indicate that inflation in countries such as Austria, Latvia, and Ireland declines the most within six to nine quarters of the shock. Correspondingly, the unemployment rate rises most sharply in Luxembourg, Latvia, Ireland, and Greece over the same horizon.

Similarly, we investigate the effects of a shock to our proxy for sovereign bond risk premiums on economic activity. The results show that an increase in this proxy generally dampens economic activity, leading to higher unemployment and lower inflation across all countries in the sample. The unemployment response is most pronounced in Greece, Spain, Slovakia, and Germany, whereas in terms of inflation, Greece, Ireland, Latvia, and Austria appear to be the most sensitive to the cyclical component of long-term interest rates.

Lastly, we introduce a brief cluster analysis to explore patterns of similarity across the Eurozone. Our modeling framework allows us to obtain clusters of economies that are most similar along the degree of association between their country-specific latent variables, namely potential output, the output gap, the natural rate of unemployment, the inflation trend, and the natural rate of interest with their common-area counterparts. We assume five clusters that capture distinct cross-country groupings, thereby highlighting the heterogeneity of structural relationships within the monetary union.

The rest of the paper is organized as follows: Section 2 describes the model and its many distinctive features. Sections 3 and 4 describe the data and estimation methodology employed, respectively. Results are introduced in section 5, while section 6 presents the study's conclusions.[2]

2 The Model

Our model for the Eurozone introduces both common-area and country-specific dynamics at the member level. We achieve this objective by (i) imposing a common factor structure on five "star" variables, namely: potential output, (y^*), the natural rate of unemployment, (u^*), the natural rate of interest, (r^*), and trend inflation, (π^*), and (ii) adding idiosyncratic components to each country's star variable. Importantly, and in contrast with the approach in González-Astudillo (2019), we impose cointegration between each country's stars variables and their common-area counterparts. The model has equations for (the log of) real GDP, the unemployment rate, the annualized quarterly inflation rate of the Harmonized Index of Consumer Prices (HICP) excluding food, energy, tobacco, and alcohol, and the 10-year government bond yield for each of the 19 countries in our sample.[3] In addition, we incorporate equations for survey data on the euro-area five-year-ahead inflation expectations and the ECB main refinancing operations rate.

In what follows, we introduce first the model equations related to real economic activity and inflation for each country. Then, we introduce the model equation for each country's long-run interest rate which influences the evolution of real economic activity and inflation via a long-run interest rate gap that is consistent with that country's level of r^*. Finally,

[2] A review of the existing literature appears in appendix A.

[3] The countries included in our sample are Austria, Belgium, Cyprus, Estonia, Finland, France, Germany, Greece, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Portugal, Slovakia, Slovenia, and Spain.

we aggregate the countries' estimates of r^*, π^*, the output gap, and four-quarter change of the core consumer prices to specify an aggregate policy rule followed by the ECB on the target policy rate. Such a rate also influences each country's economic activity and inflation through a short-run interest rate gap that is also consistent with the country's estimate of r^*.

2.1 Real Activity and Inflation

We characterize each country's (log) real GDP, y_{it}, unemployment rate, u_{it}, and inflation rate, π_{it}, for $i = 1, \ldots, n$ and $t = 1, \ldots, T$, with a standard trend-cycle decomposition approach:

$$
\begin{aligned}
y_{it} &= y^*_{it} + c_{it}, && (1) \\
u_{it} &= u^*_{it} + \theta_{i1} c_{it} + \theta_{i2} c_{i,t-1} + v_{it}, && (2) \\
\pi_{it} &= \beta_i \pi_{i,t-1} + (1-\beta_i)\pi^*_{it} + \kappa_i c_{it} + \varepsilon^{\pi}_{it}, && (3)
\end{aligned}
$$

where y^*_{it} is potential output, c_{it} is the output gap, u^*_{it} is the natural rate of unemployment, and π^*_{it} is trend inflation. In (2), we portray an Okun's law relationship with coefficients θ_{i1} and θ_{i2}, and Okun's law error $v_{it} \sim \text{iid } \mathcal{N}(0, \sigma^2_{v_i})$, whereas (3) portrays a Phillips curve relationship with expected inflation given by $\bar{\pi}_{it} \equiv \beta_i \pi_{i,t-1} + (1-\beta_i)\pi^*_{it}$, slope κ_i, and a cost-push shock $\varepsilon^{\pi}_{it} \sim \text{iid } \mathcal{N}(0, \sigma^2_{\varepsilon^{\pi}_i})$.

In turn, y^*_{it} consists of a euro-area common factor, y^*_t, with country loading δ^y_i and a country-specific component, τ^y_{it}, as follows:

$$
\begin{aligned}
y^*_{i,t} &= \delta^y_i y^*_t + \tau^y_{i,t} && (4) \\
y^*_t &= \mu^y_{t-1} + y^*_{t-1} + \eta^{y^*}_t && (5) \\
\mu^y_t &= \mu^y_{t-1} + \eta^{\mu^y}_t && (6) \\
\tau^y_{i,t} &= \mu^y_i + \tau^y_{i,t-1} + \xi^y_{i,t}, && (7)
\end{aligned}
$$

with $\eta_t^{y^*} \sim$ iid $\mathcal{N}(0, \sigma^2_{\eta^{y^*}})$, $\eta_t^{\mu^y} \sim$ iid $\mathcal{N}(0, \sigma^2_{\eta^{\mu^y}})$ and $\xi^y_{i,t} \sim$ iid $\mathcal{N}(0, \sigma^2_{\xi^y_i})$. We allow the common component of potential output to exhibit a time-varying growth rate, μ^y_t, to pick up any long-lasting movements in the common structural features of the economies associated with their potential production capabilities. Moreover, we assume the country specific component in (7) exhibits a stochastic trend with drift μ^y_i. Importantly, because y^*_t is a process integrated of order 2, or I(2), and τ^y_{it} is I(1), we impose that each country's potential output is cointegrated with the common-area factor.

Continuing with our specification, each country's output gap is dependent on an AR(2) euro-area common factor, c_t, with country loading δ^c_i and a country-specific component, υ_{it}, as follows:

$$\begin{aligned} c_{i,t} &= \delta^c_i c_t + \upsilon_{i,t} && (8) \\ c_t &= \phi_1 c_{t-1} + \phi_2 c_{t-2} + \varepsilon^c_t && (9) \\ \upsilon_{i,t} &= \phi_{i,1}\upsilon_{i,t-1} + \phi_{i,2}\upsilon_{i,t-2} + \lambda_{i,1}(R_{t-1} - \bar{\pi}_{i,t-1} - r^*_{i,t-1}) && (10) \\ &\quad + \lambda_{i,2}(R_{t-2} - \bar{\pi}_{i,t-2} - r^*_{i,t-2}) + \gamma_{i,1} c^{10}_{i,t-1} + \gamma_{i,2} c^{10}_{i,t-2} + \varepsilon^{\upsilon}_{i,t}, \end{aligned}$$

with $\varepsilon^c_t \sim$ iid $\mathcal{N}(0, \sigma^2_{\varepsilon^c})$ and $\varepsilon^{\nu}_{i,t} \sim$ iid $\mathcal{N}(0, \sigma^2_{\varepsilon^{\nu}_i})$, where R_t is the ECB (shadow) policy rate, r^*_{it} is each country's natural rate of interest, and c^{10}_{it} is a country-specific long-run real interest rate gap to be specified more precisely below. Differentiating our model from most semi-structural approaches to estimate the natural rate of interest in the literature, we assume the country-specific output gap is affected not only by lagged short-term real interest rate gaps—the terms $R_{t-s} - \bar{\pi}_{i,t-s} - r^*_{i,t-s}$ for $s = 1, 2$—as is usual in the literature (although explicitly including a real rate consistent with a shadow policy rate, which is not usual in the literature), but also by lagged long-term real interest rate gaps as in González-Astudillo and Laforte (2025) and Zaman (2025). This feature is particularly important for small open economies in which the (real) country risk premium on (long-run) sovereign debt can be a determinant of private spending decisions. For instance, Bucacos (2020) and Zarazúa Juárez

(2023) show how the spread between sovereign bond yields of small open economies and their risk free counterpart can affect private spending decisions and, ultimately, the natural rate of interest. This mechanism could prove useful to obtain an estimate of the natural interest rate of the Eurozone countries that experienced the European debt crisis.[4]

The short-term interest rate gap ensures feedback from monetary policy to economic activity and inflation. However, and importantly, we assume that the real interest rate prevalent in each country is obtained as the difference between the ECB shadow policy rate (as opposed to the observed policy rate, as in most papers in this literature) and the expected inflation rate.

Each country's natural rate of unemployment evolves according to the following process, combining both a common component, u_t^*, with loading δ_i^u and a country-specific counterpart, τ_{it}^u:

$$u_{it}^* = \delta_i^u u_t^* + \tau_{i,t}^u \tag{11}$$

$$\tau_{i,t}^u = \mu_i^u + \tau_{i,t-1}^u + \xi_{i,t}^u \tag{12}$$

$$u_t^* = \mu_{t-1}^u + u_{t-1}^* + \eta_t^{u^*} \tag{13}$$

$$\mu_t^u = \mu_{t-1}^u + \eta_t^{\mu^u}, \tag{14}$$

with $\eta_t^{u^*} \sim \text{iid } \mathcal{N}(0, \sigma^2_{\eta^{u^*}})$, $\eta_t^{\mu^u} \sim \text{iid } \mathcal{N}(0, \sigma^2_{\eta^{\mu^u}})$, and $\xi_{i,t}^u \sim \text{iid } \mathcal{N}(0, \sigma^2_{\xi_i^u})$. We also include a drift term in the common-area unemployment trend because, without it, the model would struggle to capture the block's low-frequency movements of the unemployment rates. Moreover, allowing for an idiosyncratic unemployment trend helps better match the observed unemployment rates of certain countries over the sample period. For the same reasons explained before about the cointegrating relationship between each country's potential output and its common factor, our setup imposes cointegration between each country's natural unemployment rate and the common component.

[4] There are also mechanisms that show how a higher level of government debt can increase the level of the natural interest rate (see Kocherlakota, 2015; Gamber and Seliski, 2019; Nuño, 2025, for example).

The Phillips curve in (3) ensures long-run neutrality by assuming that $\beta_i \in [0, 1)$ for all i, so each country's inflation rate converges to its trend inflation when the output gap is closed. Similarly to the previous trend variables specifications, each country's inflation trend is the sum of a euro-area common factor, π_t^*, with loading coefficient δ_i^π and a country-specific component, τ_{it}^π, as follows:

$$\pi_{i,t}^* = \delta_i^\pi \pi_t^* + \tau_{i,t}^\pi \tag{15}$$

$$\tau_{i,t}^\pi = \rho_i^\pi \tau_{i,t-1}^\pi + \xi_{i,t}^\pi \tag{16}$$

$$\pi_t^* = \pi_{t-1}^* + \eta_t^{\pi^*}, \tag{17}$$

with $\rho_i^\pi \in (-1, 1)$, $\eta_t^{\pi^*} \sim$ iid $\mathcal{N}(0, \sigma^2_{\eta^{\pi^*}})$, and $\xi_{i,t}^\pi \sim$ iid iid $\mathcal{N}(0, \sigma^2_{\xi_i^\pi})$. We note that this specification imposes that each country's inflation trend cointegrates with the I(1) common factor, as any deviation between the two, given by $\tau_{i,t}^\pi$, is stationary. Hence, all countries' inflation trends converge to the euro-area's.

Moreover, we use information from area-wide longer-run inflation expectations, denoted as π^e, to pin down the euro-area inflation trend, as follows:

$$\pi_t^e = \pi_t^* + e_{it}, \tag{18}$$

with $e_t \sim$ iid $\mathcal{N}(0, \sigma_e^2)$. This specification assumes that area-wide survey long-run inflation expectations are an unbiased estimator of the common inflation trend.

The setup we have laid out above is similar to that in González-Astudillo (2019) and would be enough to estimate common and country-specific output gaps, insofar there would be observable measures of short- and long-run interest rate gaps. These estimates of output gaps, in turn, can be used to formulate monetary policy at the euro-area level. However, this setup is not enough to robustly estimate the common and country-level natural rates of interest that will allow us to obtain the monetary policy stances for each country. To that end, we introduce below a framework that informs the natural rates of interest with data on country-level long-run interest rates as well as the ECB policy rate.

2.2 Long-run Interest Rates

Johannsen and Mertens (2021) and González-Astudillo and Laforte (2025) show that the inclusion of a long-run interest rate helps with the estimation of the natural rate of interest for the U.S. whereas Christensen and Mouabbi (2024a) show that the term structure of inflation-indexed bonds is fundamental for the euro area's estimate. Our specification of each country's 10-year government bond yield, i_{it}^{10}, is as follows:

$$i_{it}^{10} = r_{it}^* + \pi_{it}^* + p_{it}^{10} + c_{it}^{10}, \tag{19}$$

where r_{it}^* is the natural rate of interest for country i, which we assume depends on a common trend, r_t^*, through a loading δ_i^r and a country-specific component, τ_{it}^r:

$$r_{i,t}^* = \delta_i^r r_t^* + \tau_{i,t}^r \tag{20}$$

$$\tau_{i,t}^r = \rho_i^r \tau_{i,t-1}^r + \xi_{i,t}^r \tag{21}$$

$$r_t^* = r_{t-1}^* + \eta_t^{r^*} \tag{22}$$

with $\rho_i^r \in (-1, 1)$, $\eta_t^{r^*} \sim N(0, \sigma_{\eta^{r^*}}^2)$, and $\xi_{i,t}^r \sim$ iid $\mathcal{N}(0, \sigma_{\xi_i^r}^2)$. We note that this specification imposes cointegration between the country-level natural rates of interest and the common-area counterpart.

In addition, c_{it}^{10} is an AR(2) process representing any persistent but stationary deviations around the shifting endpoints $r_{it}^* + \pi_{it}^* + p_{it}^{10}$, which could capture the combined dynamics of the term or country premiums and the expected future short-run interest rate. Furthermore, to proxy for a term premium with nonstationary dynamics, we include a random walk component, p_{it}^{10}.[5] The specifications of these two processes appear below:

$$c_{it}^{10} = \psi_1 c_{i,t-1}^{10} + \psi_2 c_{i,t-2}^{10} + \varepsilon_{it}^{10},$$
$$p_{it}^{10} = p_{i,t-1}^{10} + \eta_{it}^{10},$$

with $\varepsilon_{it}^{10} \sim$ iid $N(0, \sigma^2_{\varepsilon_i^{10}})$ and $\eta_{it}^{10} \sim$ iid $N(0, \sigma^2_{\eta_i^{10}})$. We point out that the inclusion of a long-term interest rate provides signal about the low-frequency component of natural interest rates, especially at the ZLB, when the policy rate gives limited information.

To finalize our country-level specification, we allow changes in the euro-area common trend potential output growth, such as those triggered by labor supply and demographics, technological progress, physical and human capital accumulation, etc. to influence changes in the common natural rate of interest. To that end, we assume that the shocks to trend output growth, $\eta_t^{\mu^y}$, affect those of the natural interest rate, $\eta_t^{r^*}$, through a coefficient ω:

$$\eta_t^{r^*} = \omega \eta_t^{\mu^y} + \nu_t^{r^*},$$

with $\nu_t^{r^*} \sim$ iid $\mathcal{N}(0, \sigma^2_{\nu^{r*}})$. Notice that this assumption at the common-area level implies that changes in country-level natural rates of interest will be affected by changes in the country-level trend potential output growth rates.[6]

2.3 The Common Policy Framework and the Stances of Monetary Policy

Because of the single monetary policy prescribed by the ECB for all the countries of the euro area, each member faces the same policy rate, $i_t = \max\{R_t, 0\}$, where R_t is the rate that would be set by the monetary authority in absence of a lower bound on the target policy

[5] Bauer and Rudebusch (2020) provide evidence in favor of the term premium displaying non-stationary dynamics, even after accounting for a stochastic trend driving the term structure of interest rates in their specification.

[6] The relationship is as follows: $\Delta r_{it}^* = a_i \Delta \mu_{it}^y + b_i$ where $a_i = \frac{\delta_i^r \omega}{\delta_i^y}$ and $b_i = \delta_i^r \nu_t^{r^*} + \Delta \tau_{it}^r$.

rate. When $i_t = 0$, R_t is called a shadow interest rate. We assume that this interest rate is consistent with the inputs of a monetary policy rule specified as an inertial version of Taylor (1993) for each country, as follows:

$$R_t = \rho^R R_{t-1} + (1-\rho^R)\big(\tilde{r}^*_t + \tilde{\pi}^*_t + \alpha^\pi(\pi^4_t - 2) + \alpha^y \tilde{c}_t\big) + \varepsilon^R_t,$$

where $\tilde{x}_t = \sum_{i=1}^n w_i x_{it}$ is a weighted average of the country-level variables (with weights, w_i, given by the relative size of economy i as measured by its nominal GDP), for $x_{it} = r^*_{it}, \pi^*_{it}, c_{it}$, and where π^4_t is the four-quarter average of the euro-area quarterly inflation rate. Here, $\alpha^\pi > 1, \alpha^y > 0, \rho^R \in [0,1)$, and $\varepsilon^R_t \sim$ iid $N(0, \sigma^2_{\varepsilon^R})$. That is, after we get estimates of each country's variable relevant to conduct monetary policy within a Taylor rule framework, we aggregate them to specify a single euro-area monetary policy rule.

In our setup, $R^*_{it} \equiv r^*_{it} + \pi^*_{it}$ is a measure of country i's neutral nominal interest rate which is neither expansionary nor contractionary. Hence, we measure the monetary policy stance for country i as follows:

$$R_t - R^*_{it}.$$

That is, an ECB (shadow) policy rate rate, R_t, above R^*_{it} implies a contractionary monetary policy stance for country i, and viceversa. The main objective of this paper is to offer an estimate of $R_t - R^*_{it}$ for each country with associated uncertainty levels.

Notice that under this specification, the ECB policy rate informs the latent variables of each country, namely the output gap, the trend inflation rate, and the natural interest rate through country-specific weights. The larger the economy, the more signal it will obtain from the policy rate to inform its latent variables, all other things equal.

3 The Data

We use data on real GDP, the unemployment rate, consumer price inflation excluding food, energy, alcohol, and tobacco, the ECB's main refinancing operations rate for the euro area, the 10-year government bond yields, and the 5-year ahead headline consumer inflation expectations. All series come from the statistical office of the European Union, Eurostat, with the exception of the expectations data which comes from the ECB Survey of Professional Forecasters. Our sample starts in 1999:Q1 and runs through 2025:Q1. Importantly, for all countries, we consider data on the policy rate and inflation expectations only since active membership in the euro area. Appendix B details the data used.

4 Estimation

We use a Bayesian estimation that broadly follows the approach in González-Astudillo and Laforte (2025), including the treatment of the ZLB in the monetary policy rule.[7] Moreover, the estimation deals with outliers in GDP growth, changes in the unemployment rate, and inflation, using the contaminated (location-shift) normal approach described in Verdinelli and Wasserman (1991).[8]

5 Results

In this section, we first present our country- and euro area-level estimates of the interest rate gaps $R_t - R^*_{it}$, which is our measure of the stances of monetary policy, along with estimates of other latent variables consistent with those interest rate gaps. We begin by outlining the trajectory of the monetary policy stance across the sample period, placing par-

[7]The choice of prior distributions appears in appendix D.

[8]This approach allows us to obtain the size and direction of the outliers, as opposed to techniques that use a mixture of normal distributions where the variance of the observable variable is increased significantly when an outlier is detected, but there are no estimates of its direction or magnitude. The outliers detected appear in Appendix C.

ticular emphasis on episodes characterized by the greatest heterogeneity in macroeconomic outcomes. Next, we use our framework to asses the macroeconomic effects of an increase in the ECB policy rate and of a shock to country-specific long-term interest rates. Finally, we perform a clustering exercise to determine groups of countries that share commonalities in their dynamic behavior.

5.1 The stances of monetary policy across euro area members

The estimated interest rate gaps for every country of the euro area in our sample and the Eurozone estimate appear in figure 1. As indicated before, a positive interest rate gap implies that the ECB's monetary policy stance is restrictive while a negative gap indicates that it is accommodative.

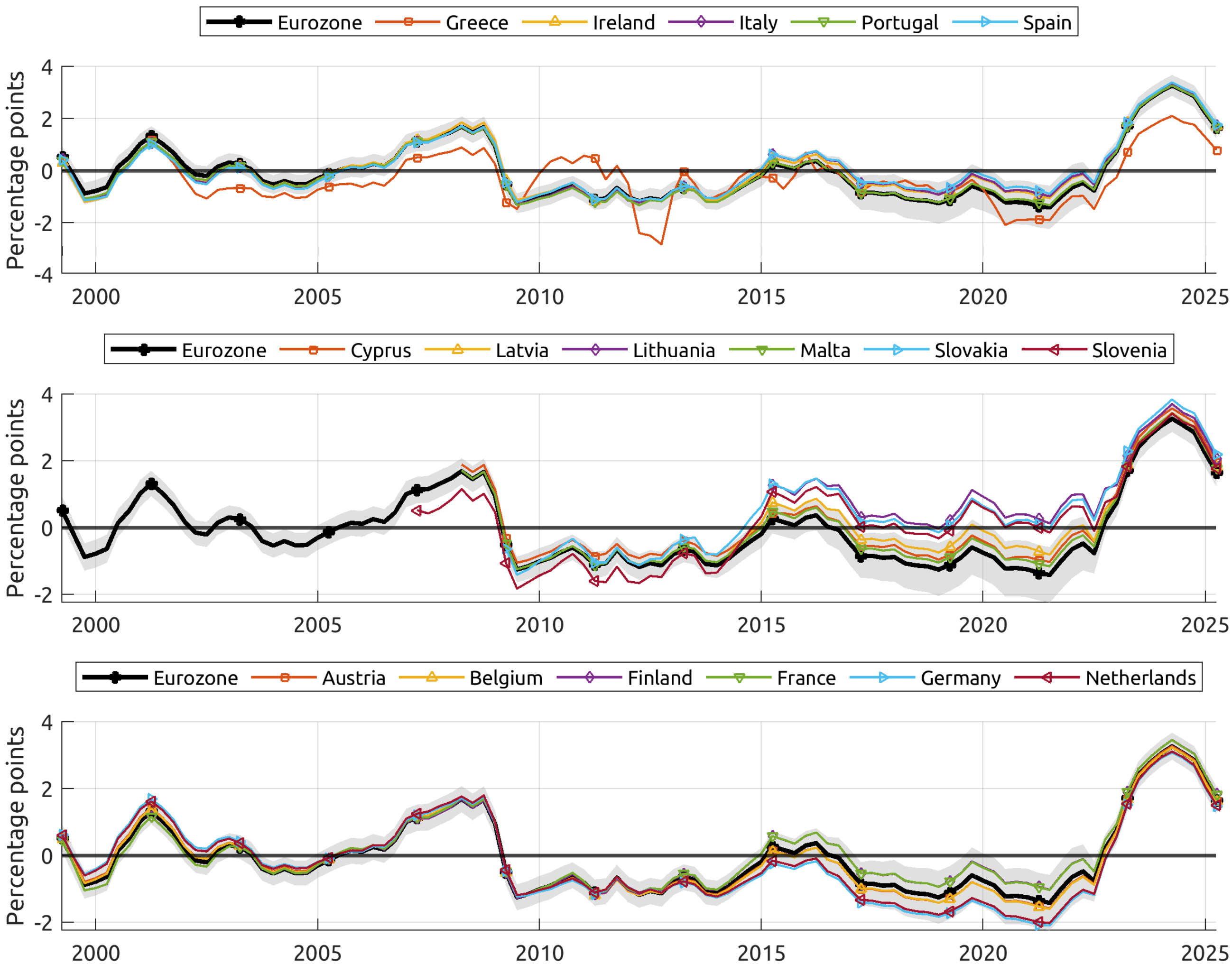
To facilitate analysis, we categorize the countries into three groups, following González-Astudillo (2019). The first group consists of economies that were most adversely affected by the European debt crisis, namely Greece, Ireland, Italy, Portugal, and Spain. The second group includes countries that joined the euro area after its initial inception in 1999 and are not part of the first group: Cyprus, Estonia, Latvia, Lithuania, Malta, Slovakia, and Slovenia. The third group comprises the original euro area members that are not included in the first group: Austria, Belgium, Finland, France, Germany, Luxembourg, and the Netherlands. For brevity, we refer to these groups as GIIPS, newcomers, and core countries, respectively.

Figure 1 underscores that, despite broadly similar monetary policy stances across countries during most of the sample period, notable cross-country divergences emerged in two episodes: the aftermath of the European sovereign debt crisis and the COVID-19 pandemic recession, including its immediate aftermath.

5.1.1 Monetary Policy Stances during the European Sovereign Debt Crisis

The first episode in our sample where monetary policy stances differ significantly amongst euro area economies was during the European sovereign debt crisis. By 2010, most Euro-

Figure 1: Estimated monetary policy stance

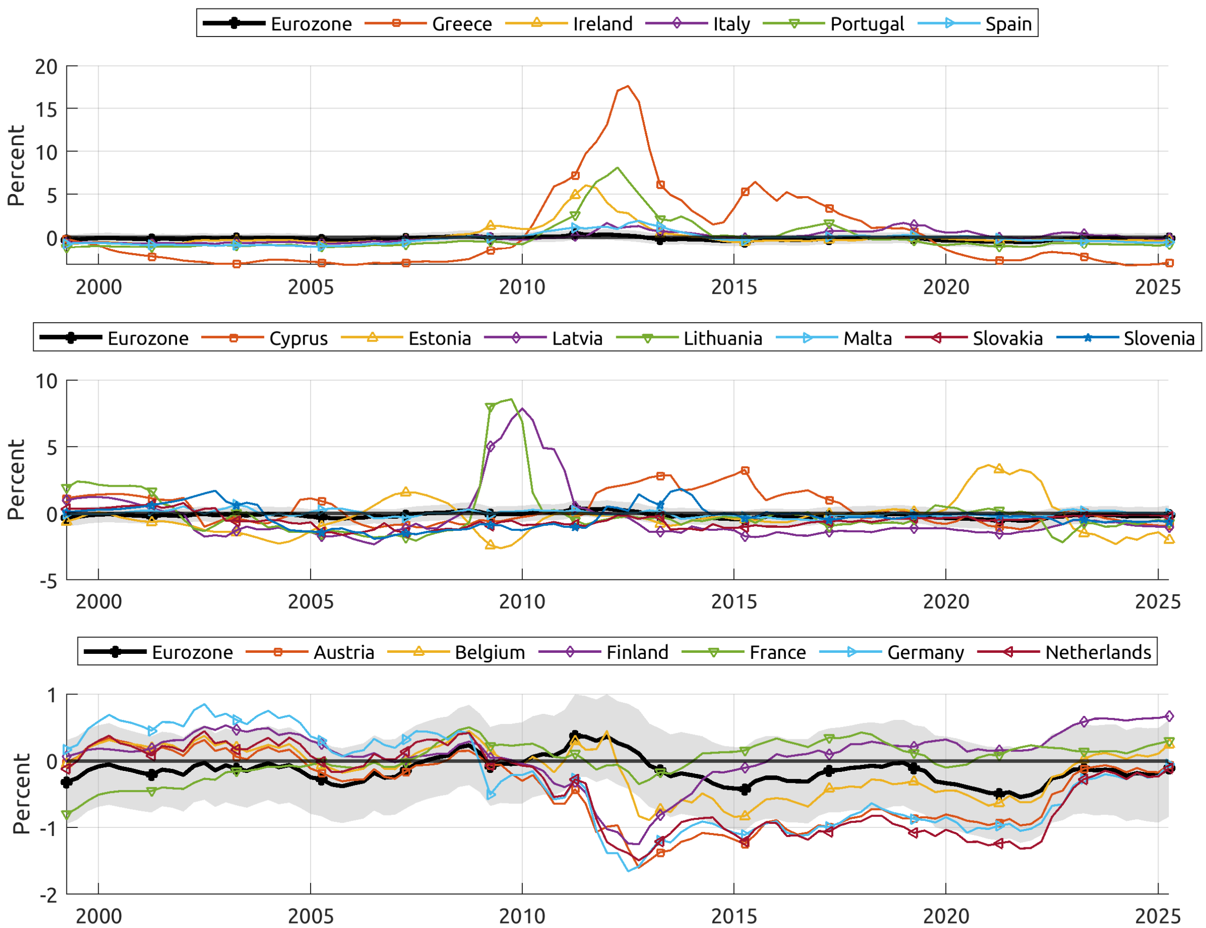


Note: The interest rate gaps for each country and the Eurozone are obtained as the difference between the ECB policy rate and our estimate of R^*_{it} when the policy rate is above the ZLB and as the difference between the implied euro-area shadow rate and R^*_{it} otherwise. Estonia is omitted from these results because missing long-term yield data for most of the sample hinders a reliable measure of the natural interest rate. The Eurozone estimate is calculated as the weighted average of all member countries in the sample. The period in the figure covers 1999:Q1 to 2025:Q1 zone countries were experiencing accommodative monetary policy conditions, leading to a rebound in economic activity, as seen in figure 3. However, as the sovereign debt crisis intensified in 2011, monetary conditions started to diverge across member states. While most economies maintained accommodative stances, others faced tight monetary conditions after 2015 that contributed to stalling the recovery. The impact was particularly severe in the GIIPS countries, where output fell significantly below potential in Greece, Portugal, Spain, and Cyprus (see figure 3). That was not the case for Lithuania, Slovakia, and Slovenia which faced similar restrictive monetary policy stances after 2015: these monetary policy conditions did not translate into weaker economic activity, suggesting a lower sensitivity of these economies to the ECB monetary policy, something we analyze in more detail in the simulation exercises below.

Indeed, it is difficult to fully interpret the evolution of the real economies in the euro area without also considering developments in financial markets, particularly sovereign borrowing costs. From this perspective, the divergence in economic outcomes during this period was also closely linked to the sharp fragmentation of Eurozone credit markets. Consistent with the findings of Carvalho (2023) and Christensen and Mouabbi (2024b), figure 2 illustrates the widening of sovereign spreads, proxied by our estimate of the cyclical component of the 10-year yields. The most severe pressures were observed in Greece, where the cyclical component of 10-year yields rose by almost 20 percentage points. Ireland and Portugal also experienced pronounced increases, with spreads exceeding five percentage points between 2010 and 2013. These surges in borrowing costs weighed heavily on financial conditions, undermining the fragile recovery that had begun in the aftermath of the Great Financial Crisis (GFC).

A few of the newcomers (middle panel of figure 2), such as Cyprus and Malta, also faced sharp increases in credit spreads, reflecting domestic crises and the limited depth of their financial markets. By contrast, core economies such as Germany, Austria, and the Netherlands consistently exhibited negative values of the cyclical component of long-

Figure 2: Estimated cyclical component of long-term yields, c_{it}^{10}



Note: The cyclical component of long-term yields for each country and the Eurozone are obtained as the difference between the 10-year government bond yield and our estimates of the sum $r_{it}^* + \pi_{it}^* + p_{it}^{10}$. The Eurozone estimate is calculated as the weighted average of all member countries in the sample. The period in the figure covers 1999:Q1 to 2025:Q1 The period in the figure covers 2001:Q1 to 2025:Q1.

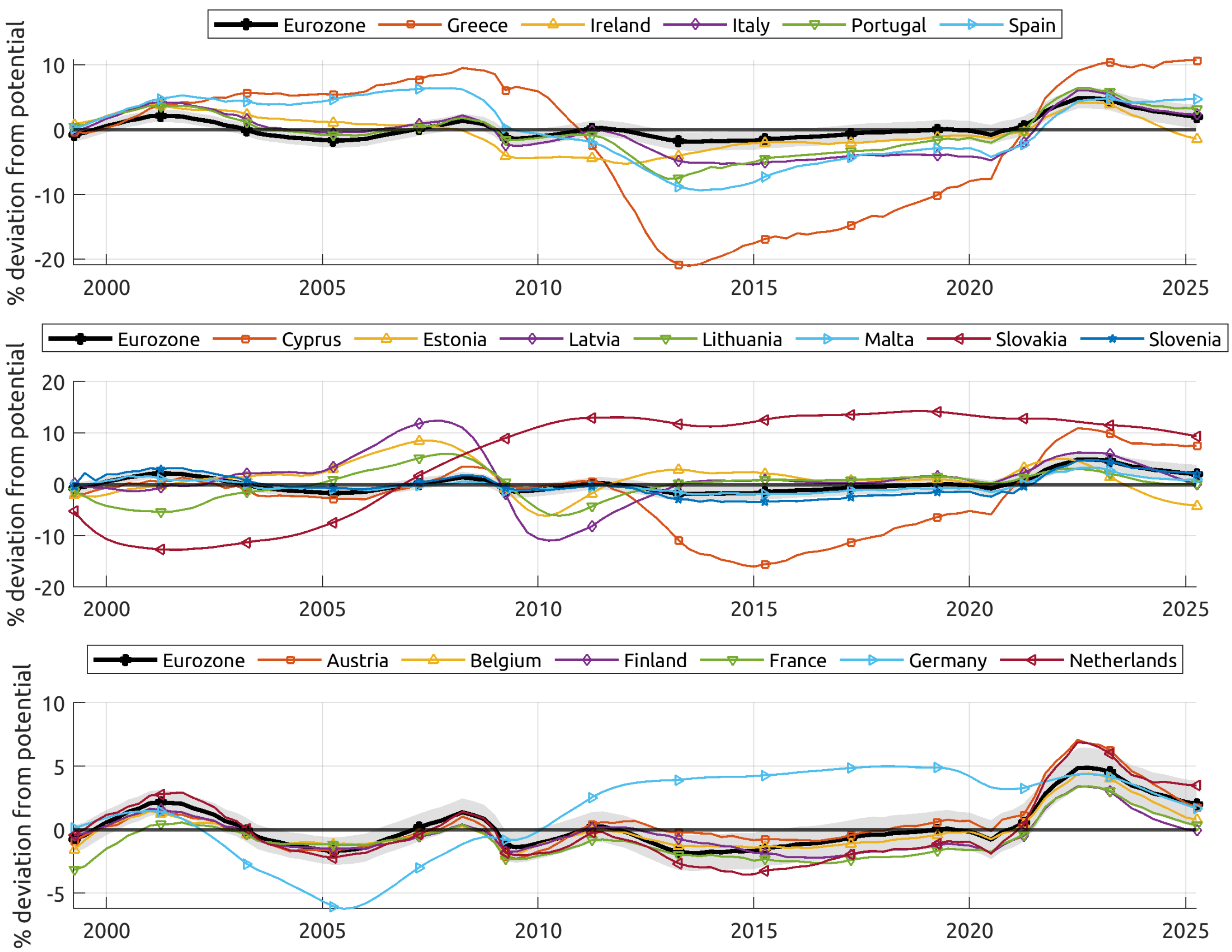
term yields, which declined steadily over the period, underscoring their safe-haven status. France and Finland remained closer to the Eurozone estimate, but experienced more modest declines. Within this group, Germany stands out as having one of the most accommodative monetary policy stances after 2015 (see bottom panel of figure 1, which helps to partially explain the country's persistently positive output gap during this period, as illustrated in the bottom panel of figure 3.

The steep rise in our proxy of sovereign risk premiums could have been therefore a key driver of tight overall financial conditions in several economies during this period. In the case of Greece, for example, the increase in borrowing costs, combined with a more restrictive stance, shifted the output gap from positive to negative territory within just a few years (see figure 3). The ECB's announcement of the Outright Monetary Transactions (OMT) program in 2012, together with unconventional measures in subsequent years, helped substantially narrow our spreads proxy. By the late 2010s, Eurozone's cyclical component of yields had largely converged toward the aggregate, although mild north–south differentials persisted.

5.1.2 Monetary Policy Stances during the COVID-19 pandemic

The second episode of pronounced heterogeneity was associated with the COVID-19 pandemic. This period ushered in highly accommodative monetary policy conditions across the Eurozone, with the ECB shadow rate, already in negative territory since 2016, falling further during 2020–2021 amid a sharp contraction in economic activity. Core economies' monetary stance generally remained close to the Eurozone aggregate, except for the Netherlands and Germany, with more accommodative conditions, and France with slightly less accommodative ones. GIIPS countries followed the Eurozone trajectory with more limited dispersion, and Greece enjoying the most accommodation. By contrast, the newcomers displayed somewhat greater heterogeneity, with Lithuania, Slovakia, and Slovenia continuing to experience slightly restrictive conditions that persisted into the subsequent years. The monetary stance

Figure 3: Output gap estimates



Note: The Eurozone estimate is calculated as the weighted average of all member countries in the sample. The period in the figure covers 1995:Q3 to 2025:Q1 began to tighten again around 2022, when the ECB initiated a rapid policy rate increase in response to mounting inflationary pressures from resource utilization and supply disruptions.

In contrast with the sovereign debt crisis, however, sovereign risk premiums did not rise significantly during the pandemic. Figure 2 shows that spreads remained largely contained despite the unprecedented fiscal expansions. Most core economies continued to enjoy safe-haven status, while spreads in the GIIPS and newcomers exhibited only limited volatility, with somewhat less divergence than in the debt crisis episode.

As mentioned before, outside these two previously described periods, the monetary policy stance was relatively uniform across the euro area. For most Eurozone countries, monetary policy was restrictive for much of the period preceding the GFC, shifted to an accommodative stance during the first half of the 2010s, and eventually returned to a restrictive stance when the global tightening cycle ensued.

In particular, most Eurozone economies experienced mostly restrictive monetary policy stances through the late 2000s. At the onset of the GFC, interest rate gaps widened markedly throughout the Eurozone, reaching peaks of around two percentage points for most member states. However, Greece represented an exception: During much of the 2000s, it benefited from relatively more favorable monetary conditions, which likely supported its robust GDP growth and sustained positive output gap well into the post-GFC period (see the top panel of figure 3).

After the GFC and before 2015, the monetary policy stances remained accomodative for most countries. As a result of the crisis, economic activity contracted sharply across the euro area, leading to a pronounced narrowing of output gaps in 2009, as shown in figure 3. These findings are consistent with those of Fries et al. (2018) for a subset of euro area economies and González-Astudillo (2019), who documents a similar pattern. The exception to this pattern is Germany, which faced the GFC with a negative output gap which eventually turned positive after 2010. Mechanically, the reason for this result follows from Okun's law: Germany's unemployment rate starts the sample at around 9 percent and increases to almost

12 percent in the second half of the 2000s, then almost steadily declines to between 3 and 4 percent since 2019; its natural rate of unemployment is estimated to have declined steadily, but not as fast as the unemployment rate itself, hence the positive unemployment rate gap before 2010 and negative thereafter.

After the pandemic and its recovery, the interest rate gap had risen to around three percentage points for most countries by the end of 2023, with Greece closer to two and Slovakia approaching four (see figure 1). At the end of the sample, all countries experienced an interest rate gap around two or less percentage points.

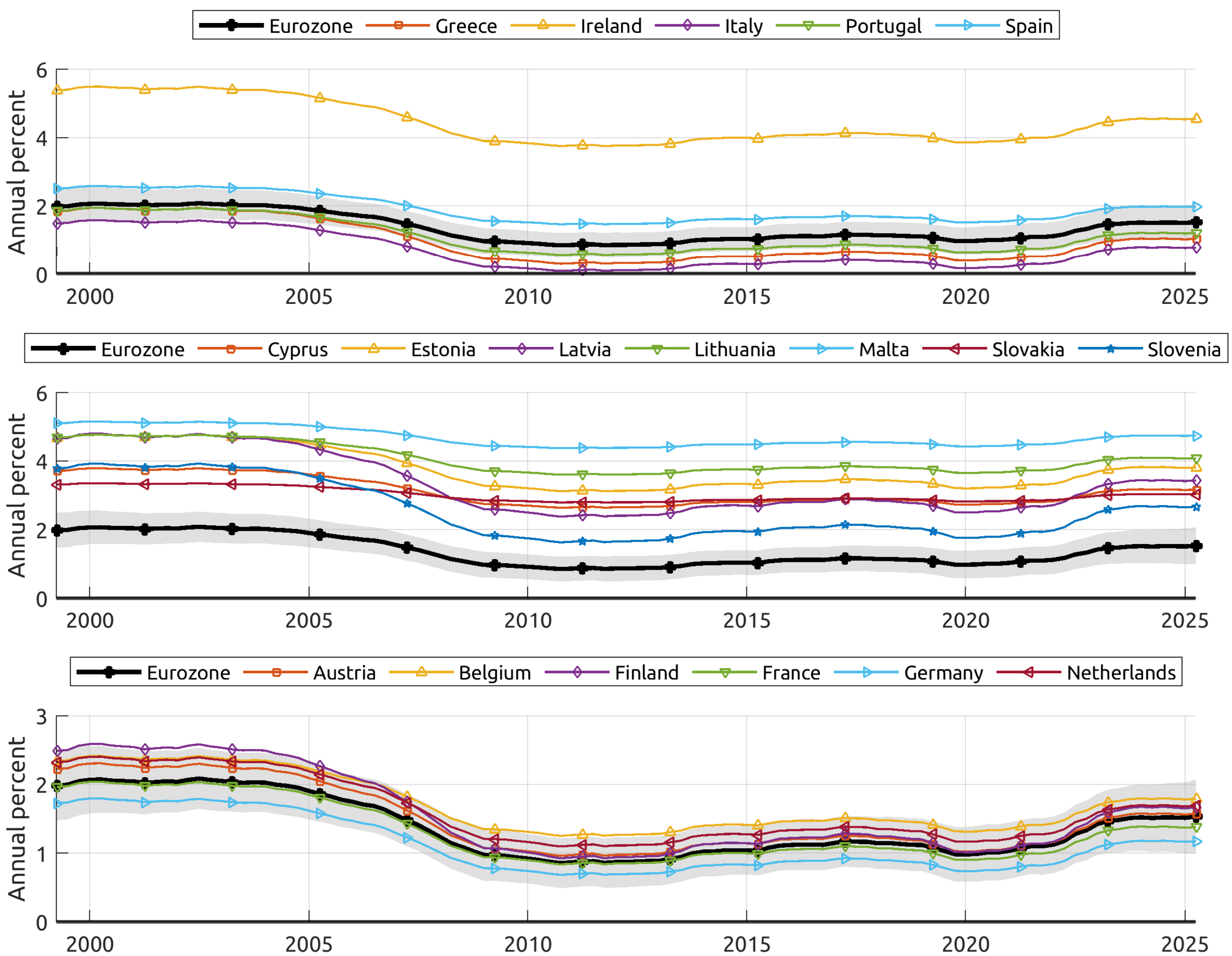
The stability of our proxy of sovereign risk premiums after the pandemic could have meant that accommodative monetary conditions were transmitted more evenly across member states compared with the sovereign debt crisis period. This relative uniformity in financial conditions underscores a key difference between the two episodes we have described: our results suggest that whereas the debt crisis amplified cross-country heterogeneity through sharply rising sovereign spreads, the pandemic period saw risk premiums relatively contained, allowing monetary policy to remain highly accommodative across most of the Eurozone and then uniformly tightened toward the end of the sample.

5.2 Trend output growth rates and the natural rates of interest

Several authors have evidenced the declining growth rates of productivity and potential output in the euro area (see Arsov, Watson et al., 2019; Silva et al., 2024; Guinea and du Roy, 2024, for example). Our results, depicted in figure 4, point in the same direction. The panel of core countries at the bottom of the figure shows almost uniformly declining trend output growth rates through 2019 with a slight improvement since 2021, reaching an average of about 1.5 percent per year in 2025.

The newcomers group in the middle panel also shows generally declining trend output growth rates albeit at a higher level, on average, and with much higher dispersion than those of the core countries. With the exception of Ireland, where rates are close to five

Figure 4: Estimates of trend output growth rates



Note: The potential output growth rate is measured in quarterly annualized percent as $4 \times \mu_{it}$. The Eurozone estimate is calculated as the weighted average of all member countries in the sample. The period in the figure covers 1995:Q3 to 2025:Q1 percent, the GIIPS countries in the top panel generally exhibit lower trend output growth rates, with variation levels comparable to those of the newcomers over the sample period. The similarities in the trajectories depicted in figure 4 are a feature of the cointegrating relationships imposed between the country-level potential output processes, y^*_{it}, and the common factor, y^*_t.[9]

We now turn to describe the estimates of the natural rates of interest, r^*, by country, as their evolutions are connected with those of the trend output growth rates in our model via their respective shocks that are correlated.[10] Our results show that the correlation coefficient between the shocks to the growth rate of common trend output, μ^y_t, and those of the common natural rate of interest, r^*_t has a posterior mean around 0.17, not far from the implied correlation coefficient between these two shocks in the results of Brand and Mazelis (2019), around 0.23.[11] Figure 5 shows the results. As expected from the evolution of the trend output growth rates and the positive correlation coefficient between the shocks we described above, there is also an overall downward trend in our estimates of r^* for all the countries of the Eurozone, especially until the onset of the COVID-19 pandemic. This is in line with other studies such as Brand, Bielecki and Penalver (2018), Fiorentini et al. (2018), and others who report similar findings. Starting in 2022, our estimates of the natural interest rate have increased for all countries, influenced in part by stronger potential output growth.

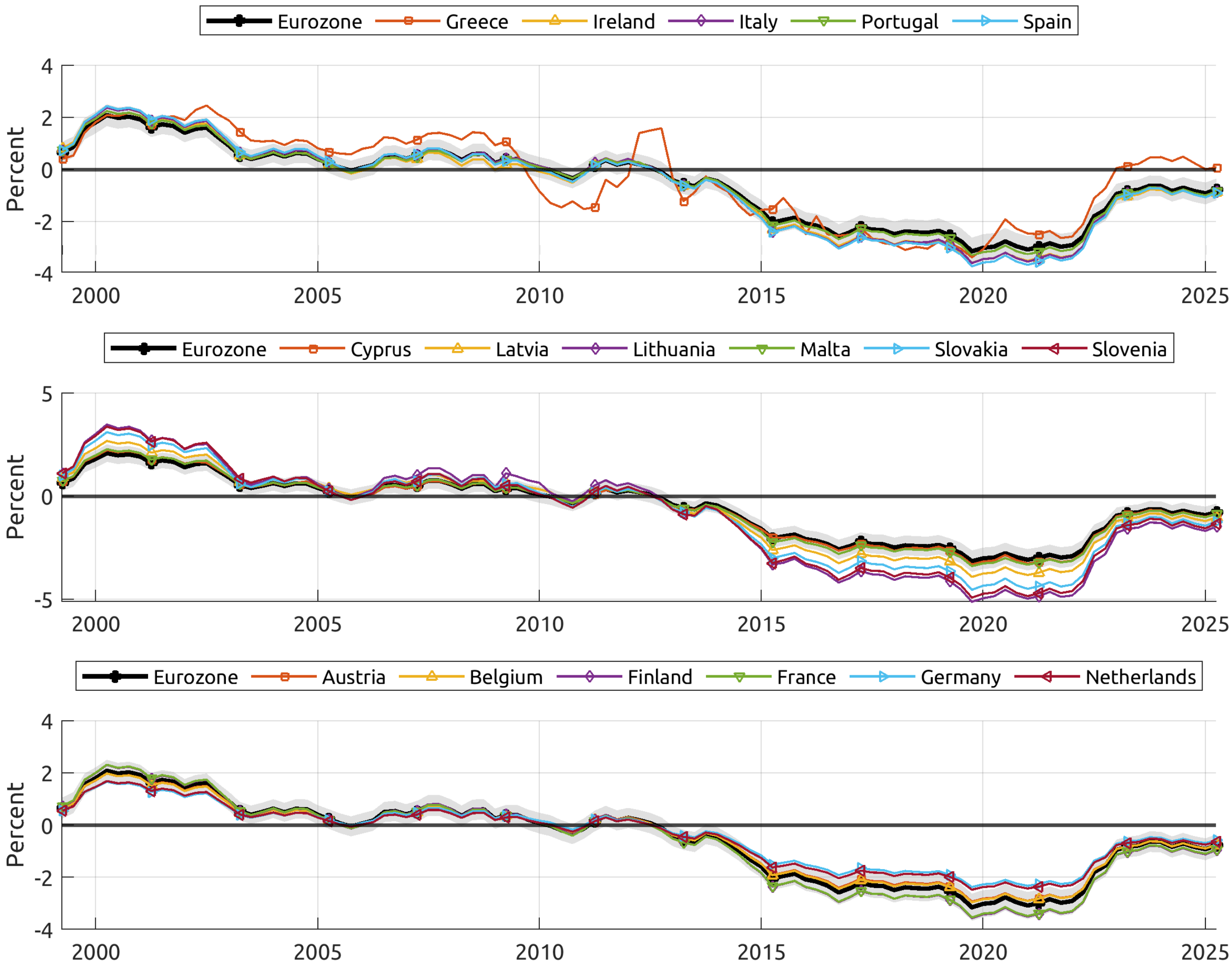
While the overall trend is broadly similar across Eurozone economies, notable differences emerge across the three country groups. Core countries display limited within-group variation, with most natural rates peaking at around 2 percent in the early 2000s and reaching their lowest levels, between negative 2 and 3 percent, during the pandemic. While natural rates in the core group uniformly declined and turned negative in the aftermath of the European debt crisis, the newcomers group followed a similar trajectory but with greater

[9]The trend growth rate of country's i potential output is given by $\mu^y_{it} = \delta^y_i \mu^y_t + \mu^y_i$.

[10]Note that Estonia is omitted from these results because missing long-term yield data for most of the sample hinders a reliable measure of the natural interest rate.

[11]Recall that for each country, this correlation coefficient needs to be weighed by the corresponding loading coefficients δ^y_i and δ^r_i to obtain the country-specific correlation coefficients.

Figure 5: r^* estimates



Note: The Eurozone estimate is calculated as the weighted average of all member countries in the sample. Estonia is omitted from these results because missing long-term yield data for most of the sample hinders a reliable measure of the natural interest rate. The period in the figure covers 1995:Q3 to 2025:Q1 heterogeneity. In the years preceding the pandemic—and even in some years thereafter—most countries in this group recorded natural rates below the Eurozone estimate. In some cases, such as Lithuania and Slovenia, natural rates fell to nearly negative 5 percent.

Finally, countries in the GIIPS group exhibit broadly similar and smooth trajectories in their estimated natural rates of interest—initially positive, hovering around zero or slightly above prior to the GFC, turning negative thereafter and through the pandemic period, and converging back toward zero at the end of the sample. Greece, once again, stands out, as its estimated natural interest rate displays considerable variability over time and ends the sample slightly above zero. Similar to the newcomers group, the remaining countries in this group such as Spain, Italy and Portugal, generally record natural rates at or slightly below the Eurozone estimate.

5.3 Monetary policy transmission across countries

In this section, we aim to gain a deeper understanding of the model's single monetary policy transmission mechanism across countries. To do so, we simulate a positive one-percentage point increase in the policy rate that lasts for four quarters, after which it returns to its original level. Figure 6 shows the responses of the unemployment rates while figure 7 shows those of the inflation rates. Of note, our results obtain posterior means for the coefficients of the policy rule as follows: $\rho^R = 0.85$, $\alpha^\pi = 1.3$, and $\alpha^y = 0.5$, with a standard deviation of the monetary policy shock, $\sigma_{\varepsilon^R} = 0.37$.

As expected, tighter monetary policy depresses economic activity and lowers inflation. Our results indicate that the largest increases in unemployment within each country group occur in Greece, Latvia, and Luxembourg (figure 6), while the largest declines in inflation are observed in Greece, Latvia, and Austria (figure 7). There is also substantial heterogeneity in the persistence of these responses, with some economies recovering more quickly than others. For instance, unemployment remains elevated in Greece and Latvia even 20 and 18 quarters, respectively, after the initial policy rate increase, whereas countries such as Italy, Portugal, Lithuania, and Slovenia return to baseline levels within roughly three years or less. Other economies, such as Slovakia, exhibit a more muted yet persistent response, consistent with the country's sustained positive output gap despite a persistently restrictive monetary policy stance. This heterogeneity of outcomes likely reflects a combination of factors, including differences in the importance of interest rate–sensitive sectors, institutional characteristics of labor markets, and variations in stages of economic development across Eurozone countries. More importantly, these differences underscore the challenges of implementing a common monetary policy with a single interest rate instrument.[12]

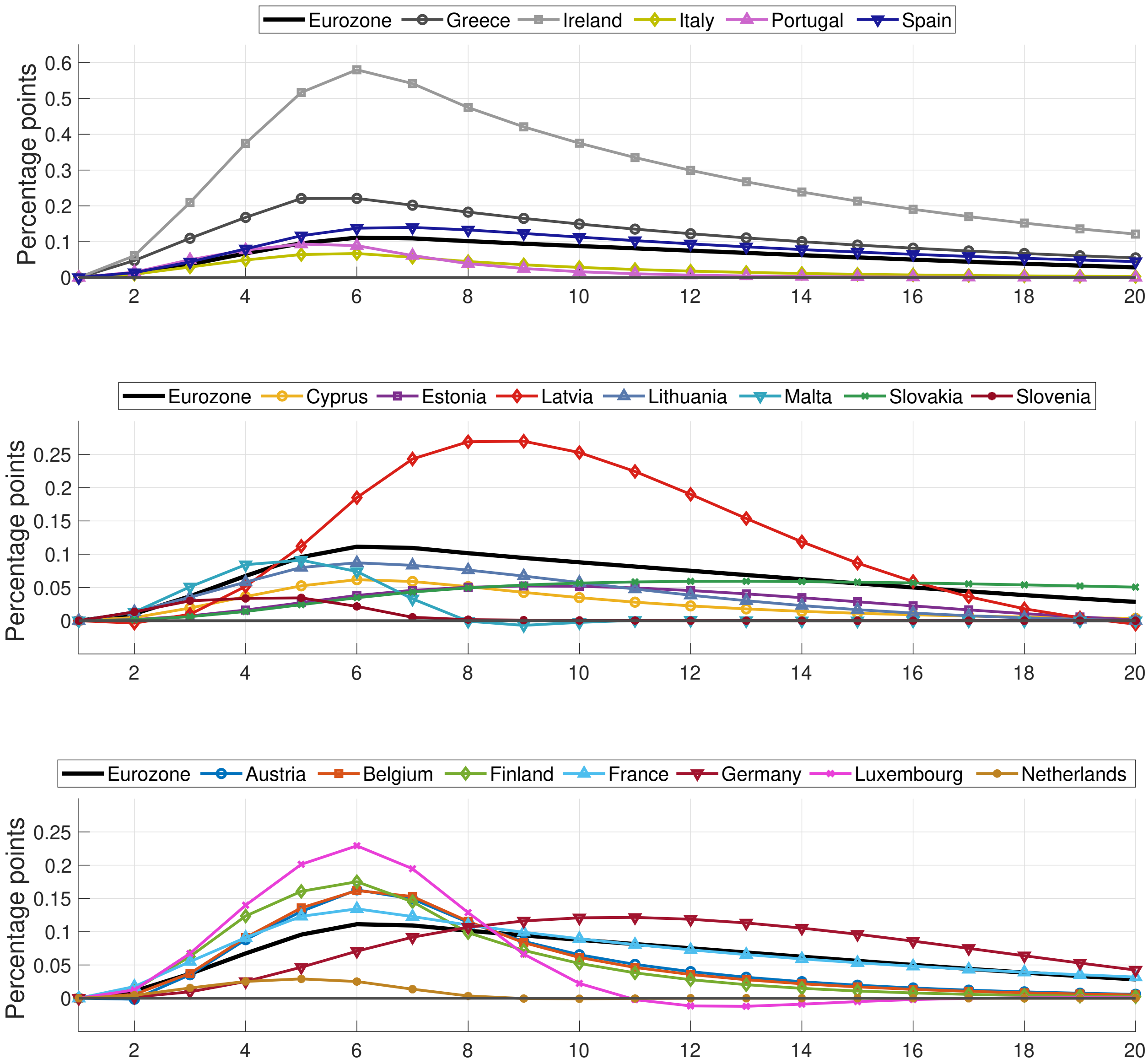
5.4 The effect of government debt yield shocks

While the results presented in figures 6 and 7 provide valuable insights into the monetary policy transmission mechanism in the Eurozone, it is also important to consider the effects of the cyclical dynamics in long-term interest rate cycles, c_{it}^{10}, which we are using as a proxy of sovereign bond risk premiums. As previously discussed, incorporating this proxy into our model allows us to more accurately assess the monetary policy stance for several economies in our sample. Figures 8 and 9 illustrate the impact on inflation and the unemployment rate of a temporary shock to c_{it}^{10}, scaled by the standard deviation of each country's innovation.

An increase in our proxy for bond risk premiums dampens economic activity, leading to higher unemployment and lower inflation across all countries in the sample. The unemployment response is most pronounced in Greece among the GIIPS countries, Slovakia among the newcomers, and Germany among the core economies. Greece's response, in particular, reflects a high degree of sensitivity to long-term interest rates and is consistent with the output gap dynamics observed during the European debt crisis. Germany, by contrast, exhibits a relatively milder yet highly persistent unemployment response, which aligns with the enduring dynamics of its positive output gap (figure 3) and negative cyclical component

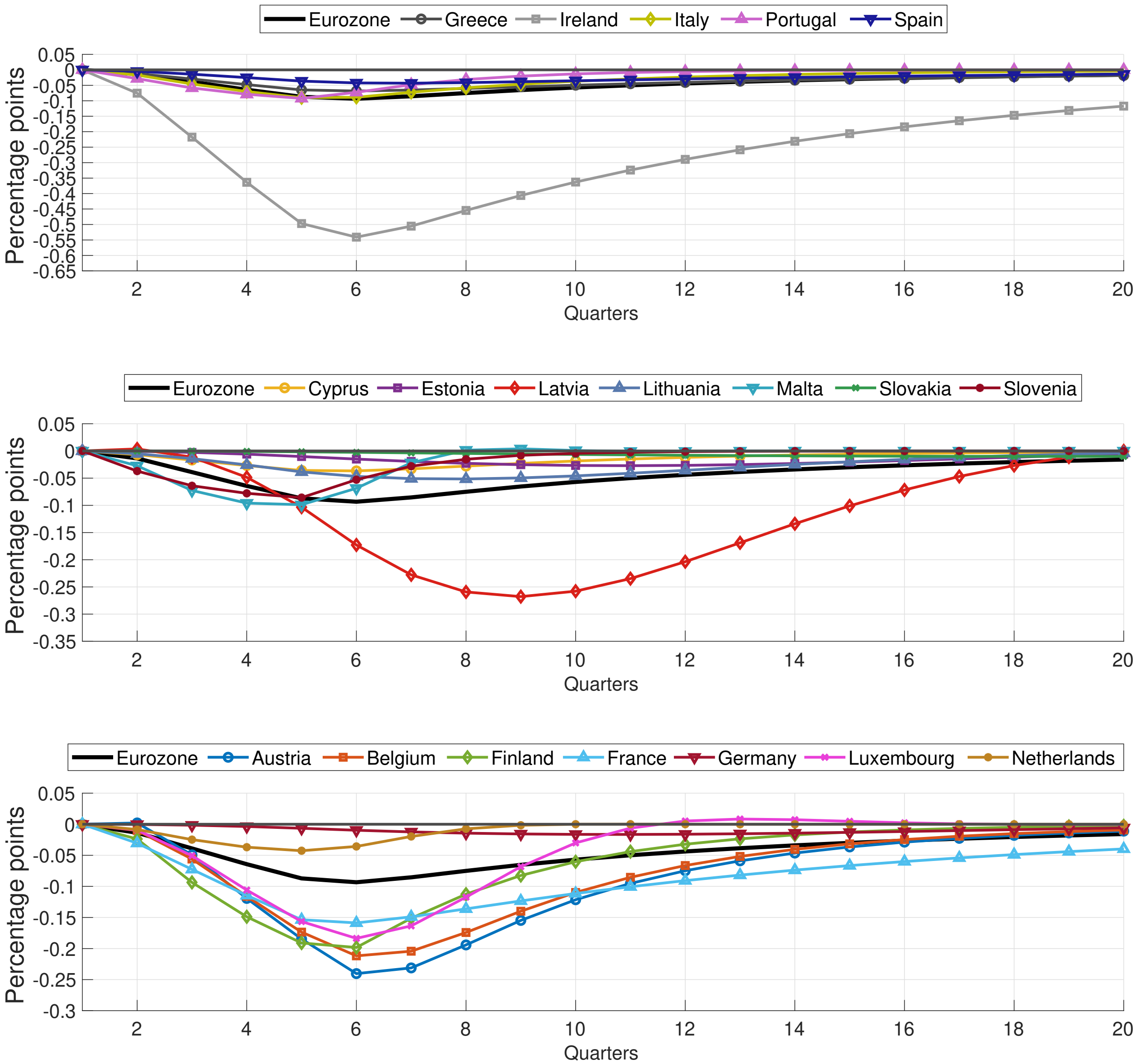
[12] Mandler, Scharnagl and Volz (2022) show that real output responds more strongly to monetary policy in Germany than in other countries, whereas the price level response is strongest in Spain and weakest in Germany.

Figure 6: Response of the unemployment rate to a policy rate shock



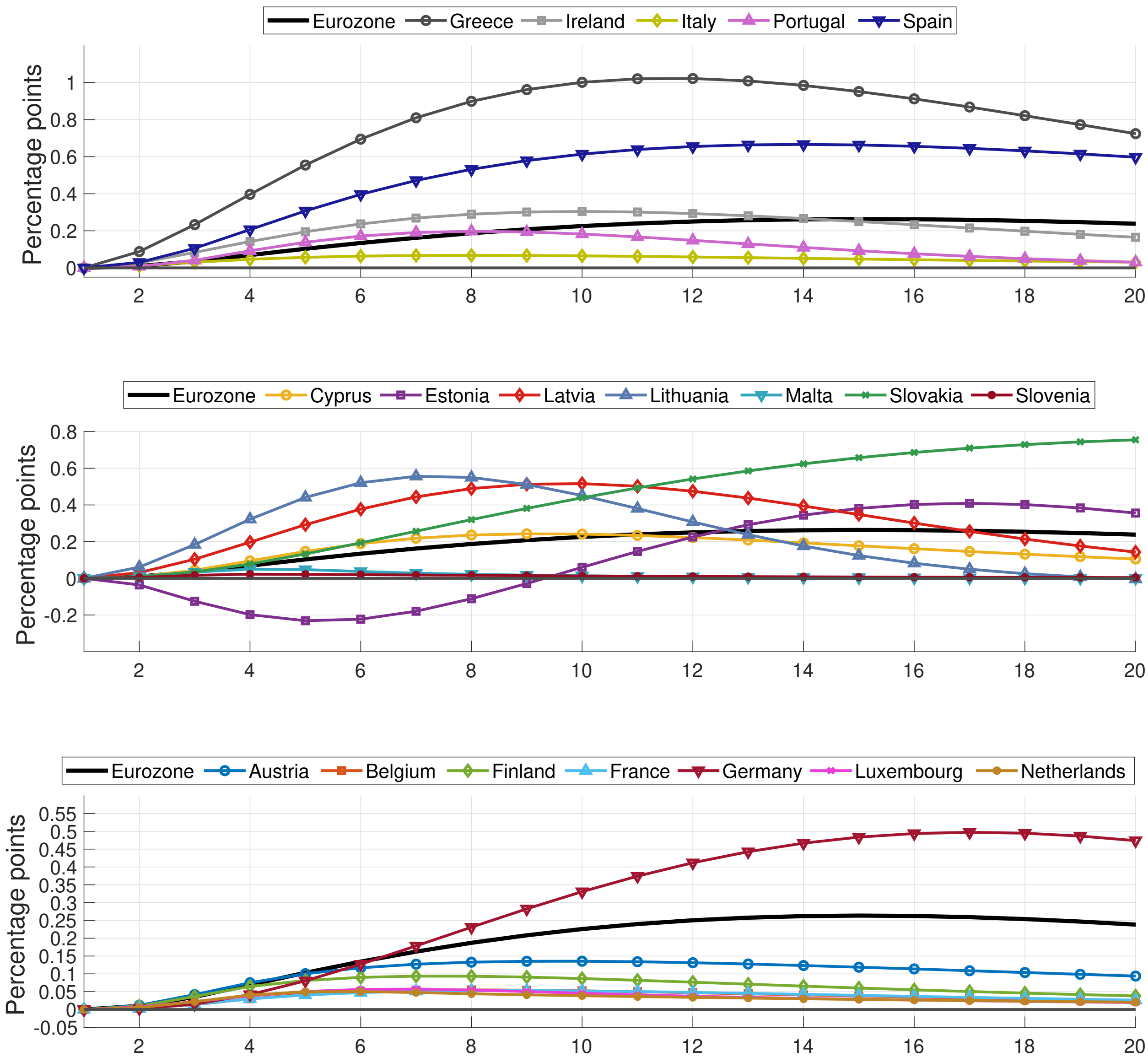
Note: The policy rate, R_t, is increased by one percentage point for four quarters and then it returns to its steady-state level.

Figure 7: Response of the inflation rate to a policy rate shock



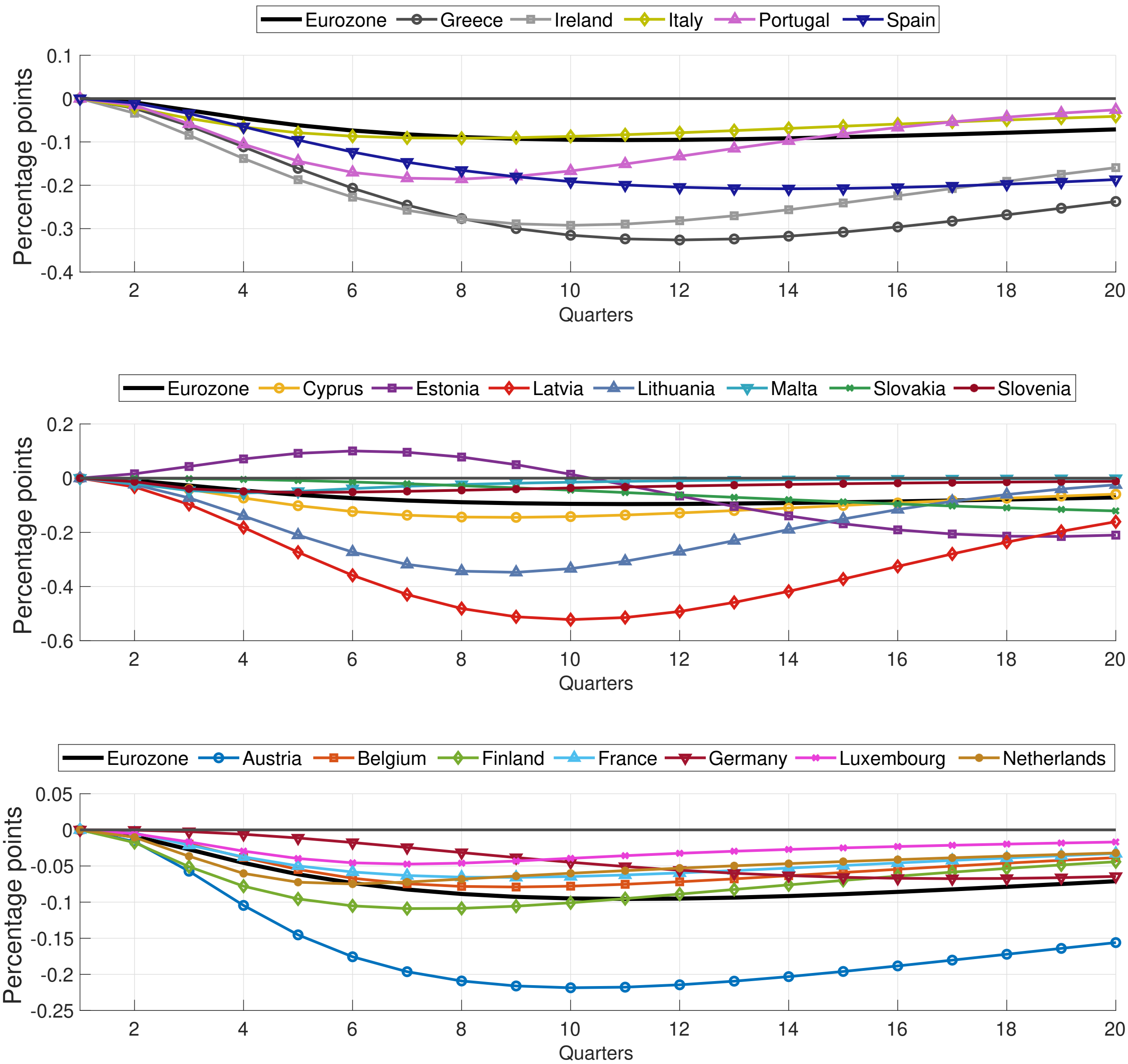
Note: The policy rate, R_t, is increased by one percentage point for four quarters and then it returns to its steady-state level.

Figure 8: Response of the unemployment rate to a long-term interest rate shock



Note: The shock corresponds to a one standard deviation of, ε_{it}^{10}, the innovation to the cyclical component of the 10-year government bond yield, for one period.

Figure 9: Response of the inflation to a long-term interest rate shock



Note: The shock corresponds to a one standard deviation of, ε_{it}^{10}, the innovation to the cyclical component of the 10-year government bond yield, for one period.

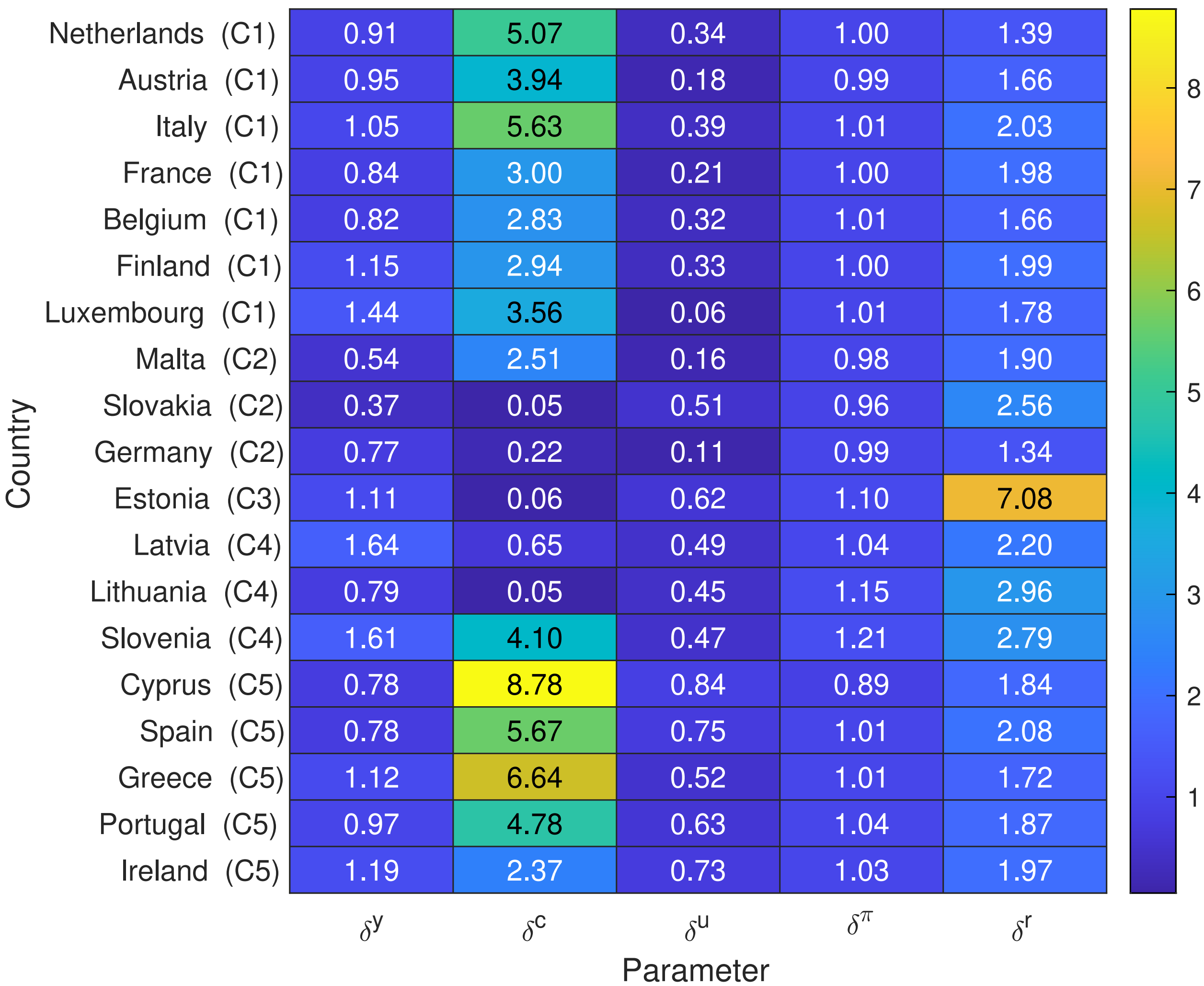
of long-term yields (figure 2) during the sample period. Regarding inflation, Greece and Ireland within the GIIPS group, Latvia among the newcomers, and Austria among the core economies appear to be the most sensitive to the cyclical component of long-term interest rates. In Greece, inflation declines by about 30 basis points after 10 quarters, compared with roughly 20 basis points in Austria, and close to 60 basis points in Latvia.

The heterogeneity in the estimated long-run interest rate elasticities indicates that this channel can be important to disentangle and assess the stance of monetary policy that each country faces. For example, GIIPS economies such as Greece and Spain display strong responses in both unemployment and inflation, a pattern consistent with developments observed during the height of the European debt crisis in 2011–2013. Among the core countries, the effects of such shocks on economic activity and inflation are generally more muted, with the notable exceptions of Germany, where unemployment rises persistently, and Austria, where inflation declines more markedly. Although less pronounced than in Greece, the increase in unemployment in Germany and the decline in inflation in Austria are still considerably larger than those observed in the rest of the core economies. Taken together, these results underscore the considerable heterogeneity in transmission across member states, highlighting the inherent challenges of conducting a common monetary policy with a single policy instrument in a diverse currency union.

5.5 Clustering the euro area economies

This section uses the results of the common factors specification to obtain clusters of economies that are most similar along the degree of association between their country-specific latent variables, namely potential output, the output gap, the natural rate of unemployment, the inflation trend, and the natural rate of interest with their common-area counterparts. To that end, we obtain the posterior means of the loading coefficients $\delta_i^y, \delta_i^c, \delta_i^u, \delta_i^\pi, \delta_i^r$, for $i = 1, ..., n$ and perform a cluster analysis in which we assume five groups. Figure 10 summarizes the results.

Figure 10: Clusters implied by loading coefficients



Note: Graph report raw coefficient values.

Each row in the heatmap corresponds to a country, and each column corresponds to one of the five parameters (δ^y, δ^c, δ^u, δ^π, δ^r). The numbers in the cells report the parameter values, while the shading indicates their magnitude according to the color bar on the right: darker blue tones represent lower values, green shades indicate moderate values, and yellow tones capture the largest values in the sample. Countries are grouped by cluster, shown in parentheses after the country name (e.g., C1, C2), so that countries with similar color patterns across the five parameters appear together. Reading across a row shows a given country's loading coefficient, while reading down a column reveals how the loading coefficients differ across countries.

The heatmap highlights striking cross-country heterogeneity in the five parameter loadings. The first cluster (C1) is comprised of countries whose natural unemployment and interest rates are less connected with the corresponding common factors. All countries in this cluster, except, Italy, belong to the core set. This finding suggests they are more insulated from economically meaningful structural changes occurring at the euro area level. In a second cluster (C2), with countries whose potential output and output gap are the least connected with the common factor counterparts, we have Germany, Malta, and Slovakia. Figure 3 shows that Germany and Slovakia have output gap trajectories that are very different from the rest of the countries in our sample. Like those in the first group, the results suggest these countries are not significantly affected by output developments at the euro area level. The third cluster (C3) is a singleton, with Estonia in it. Unfortunately, the lack of data on the long-run interest rate for Estonia makes it very difficult for the model to obtain a reasonable estimate of the natural rate of interest, which clouds obtaining other latent variables consistent with it. In the fourth cluster (C4), we have countries whose potential output and trend inflation are the most linked with the corresponding common factors. All countries in this cluster belong to the newcomers group. Finally, the last cluster (C5) involves countries from the GIIPS group (except Italy) and Cyprus, with a feature such that their output gaps and natural rates of unemployment are more strongly connected with the common-area counterparts.

6 Conclusion

This paper assesses the country-level monetary policy stances in 19 Eurozone economies over the 2000–2025 period. To achieve this goal, we postulate a semi-structural model that jointly estimates the dynamics of inflation, unemployment, real GDP, and interest rates to derive their long-run counterparts—the so-called "stars." Using these estimates, we construct a measure of the interest rate gap for individual Eurozone member countries. This analysis provides insights into the degree of heterogeneity in the monetary policy stance, as well as its effects and persistence across member states.

Our findings indicate synchronization in the monetary policy stance across Eurozone economies for most of the sample period, with divergences arising during two particular episodes: the European sovereign debt crisis and the COVID-19 pandemic. In the former, several GIIPS countries, notably Greece, Ireland, and Portugal, faced significantly more restrictive financial conditions as long-term yields surged. By contrast, many core economies benefited from flight-to-quality flows, which drove their yields downward and reinforced their safe-haven status. These developments likely hindered the uniform transmission of monetary policy across the euro area. In the latter episode, some countries—-such as Lithuania, Slovakia, and Slovenia—registered positive interest rate gaps during this period, as opposed to the rest of the countries, highlighting the complexities of formulating monetary policy in a heterogeneous currency union.

Additionally, we find significant heterogeneity in both the transmission and persistence of monetary policy across member countries. Our impulse-response analysis suggests that economies such as Ireland, among the GIIPS, and Latvia, among the newcomers, exhibit relatively high interest rate sensitivity. Within the core countries, Luxembourg emerges as the most responsive economy in terms of unemployment. With respect to inflation, a similar pattern holds: Ireland among the GIIPS and Latvia among the newcomers display the highest elasticities, while Austria, among the core economies, records the strongest responsiveness to changes in the policy rate.

Overall, this paper offers a fresh perspective on some of the fundamental challenges of conducting monetary policy within a currency union. Differences in economic structures, macroeconomic fundamentals, and transmission mechanisms highlight the limitations of relying on a single common interest rate instrument. However, we see important room for improvement in our modelling strategy going forward: First, the model can introduce equations for aggregate measures of output and unemployment, such that estimates of the euro area output gap obtained from aggregating the country-specific estimates are more consistent with those obtained from estimating the same model on aggregate Eurozone data. Second, the model can include stochastic volatility specifications that allow us to estimate more cleanly the latent variables, isolating the effects of noisy data due to volatile periods in our sample. Third, we need to validate our setup by running pseudo out-of-sample forecasting exercises. For instance, we can compare the forecasting performance of our model against that of a model estimated separately for each country, or a model that does not impose cointegration between country-specific and common stars.

Appendix

A Literature Review

The natural rate of interest (r^*) has been a cornerstone of monetary policy analysis, providing a benchmark for assessing the stance of policy relative to economic equilibrium. Despite its theoretical appeal, estimating r^* poses significant challenges due to its unobservable nature and its sensitivity to data and methodological assumptions. This section reviews the existing literature on r^* estimation, highlighting key methodologies, their applications to advanced economies, and the specific challenges faced within the European Monetary Union (Eurozone).

Seminal contributions to the estimation of r^* were made by Laubach and Williams (2003), who introduced a semi-structural state-space model incorporating macroeconomic trends such as potential output and inflation. This framework provided a foundation for subsequent studies, including Holston, Laubach and Williams (2017), which extended the methodology to a broader set of advanced economies. These studies underscored a global decline in r^* attributed to structural factors such as demographic shifts, productivity slowdowns, and heightened demand for safe assets.

In the context of multi-country frameworks, studies such as Brand and Mazelis (2019) and Obstfeld (2023) explored the heterogeneity of r^* across countries and its implications for monetary policy. These works integrated Bayesian estimation techniques and factor-augmented models to account for cross-country interactions and shared global trends, offering a more comprehensive understanding of r^* dynamics. Similarly, efforts to apply r^* estimation techniques to the Eurozone highlighted unique challenges arising from its multi-country structure and shared monetary policy. For instance, Brand, Bielecki and Penalver (2018) and Bofinger and Haas (2023) emphasized the importance of incorporating country-specific dynamics, while Christensen and Mouabbi (2024a) and Christensen and Rudebusch (2019) explored the role of financial markets in shaping r^*.

The literature on r^* estimation has also identified several methodological challenges. Sensitivity to data selection and prior distributions remains a critical issue, as highlighted by Cesa-Bianchi, Harrison and Sajedi (2022). Additionally, the integration of monetary policy rules into r^* estimation frameworks has been inconsistent across studies. Notably, González-Astudillo and Laforte (2025) addressed these gaps by embedding a monetary policy framework within a semi-structural model. Another persistent challenge involves the aggregation of r^* estimates in the context of the Eurozone, where the heterogeneity of economic conditions across member states complicates the estimation process, as noted by the Fries et al. (2018).

Building on these foundations, this paper introduces a novel approach to estimating r^* for the Eurozone that addresses the limitations of prior studies. Inspired by the methodology of González-Astudillo and Laforte (2025), we develop a state-space framework that jointly models trend and cyclical factors while explicitly incorporating a monetary policy rule tailored to the Eurozone context. Unlike prior studies that rely on a limited set of observables, our model utilizes a comprehensive dataset of 82 observables, capturing the diverse macroeconomic conditions across Eurozone member states. By accounting for country-specific dynamics and allowing for correlated innovations in trend components, our framework provides a more nuanced understanding of r^* within the Eurozone.

B Data details

We set the initial sample starting date as the first observation of unemployment for country-specific data and the eurozone, and the sample runs through 2024:Q3. Specifically, the sample begins in 2000:Q1 for the Eurozone, Cyprus, and Malta; 2000:Q2 for Estonia; 1998:Q2 for Greece; 1996:Q1 for Slovenia; 1998:Q1 for Latvia, Lithuania, and Slovakia; and 1995:Q3 for all other countries.

- Real GDP: Harmonized ESA Real GDP, millions of chained 2020 euroes, seasonally adjusted, level, quarterly frequency from Statistical Office of the European Communities/Haver Analytics.

- Nominal GDP to compute weighted shares: Harmonized ESA, millions of chained 2010 euroes, seasonally adjusted, level, quarterly frequency from Statistical Office of the European Office/Haver.

- Unemployment: Harmonized total unemployment rate Age 15-74, Seasonally adjusted, percentage, monthly frequency from Statistical Office of the European Communities/Haver.

- Inflation country specific: Harmonized Indices of Consumer Prices (HICP) less energy, food, alcohol & tobacco, level, Index 2015=100, seasonally adjusted, monthly frequency from Statistical Office of the European Communities/Haver.

- Inflation Eurozone: Harmonized Index of Consumer Prices: Overall Index Excluding Energy, Food, Alcohol, and Tobacco for Euro area (19 countries), index 2015=100, level, seasonally adjusted through eviews X13, monthly frequency from Eurostat/Fred.

- Inflation Expectations: ECB Survey of Professional Forecasters, EA 11-20: SPF Inflation Forecast, Mean Point Estimate, Long term, four calendar quarters ahead in Q1 and Q2 rounds and five calendar years ahead in the Q3 and Q4 rounds, Y/Y percent change, quarterly frequency from European Central Bank/Haver.

- Interest rate: Euro Area 11-20: Main Refinancing Operation on Effective Date, end of period, percent per annum, monthly frequency from European Central Bank/Haver.

- Long term interest rates/Bond yields: Market Yields of Government Bonds with Average Maturity of 10 years, average yield, percentage, monthly frequency from European Central Bank/Haver.

C Outlier Analysis

Figure C.1: GDP growth outliers (percent)

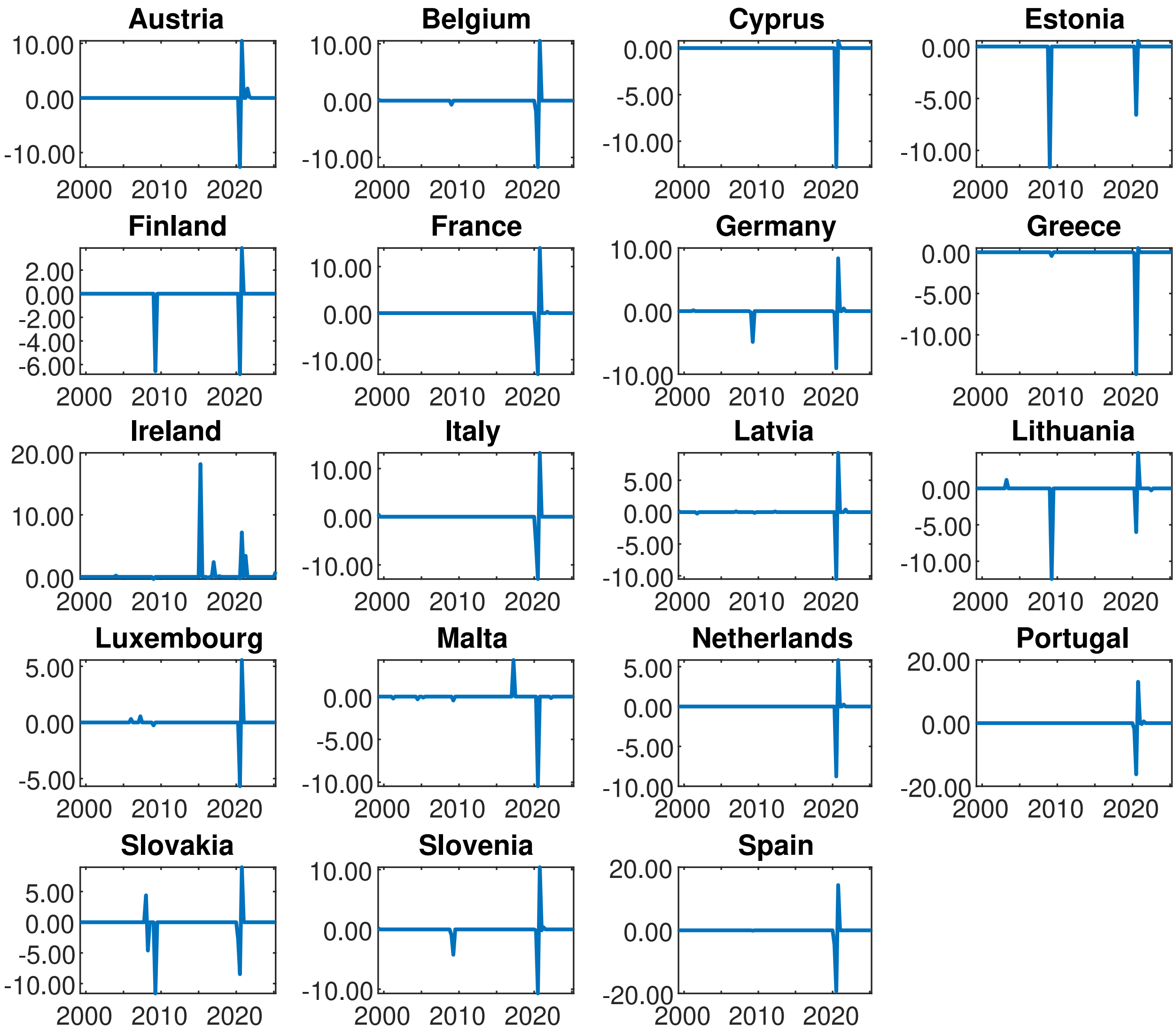


Figure C.2: Estimated Inflation outliers (percentage points)

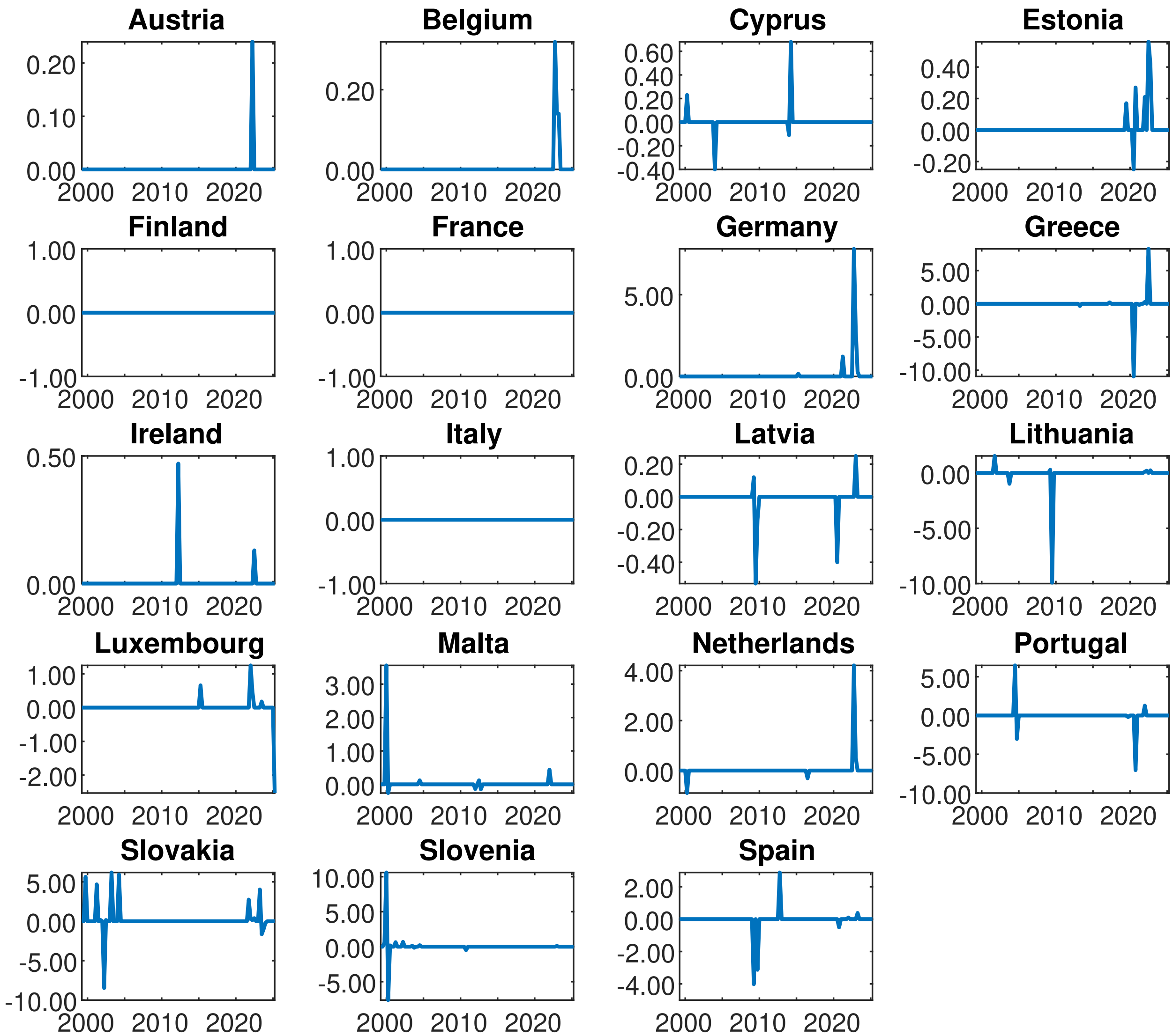
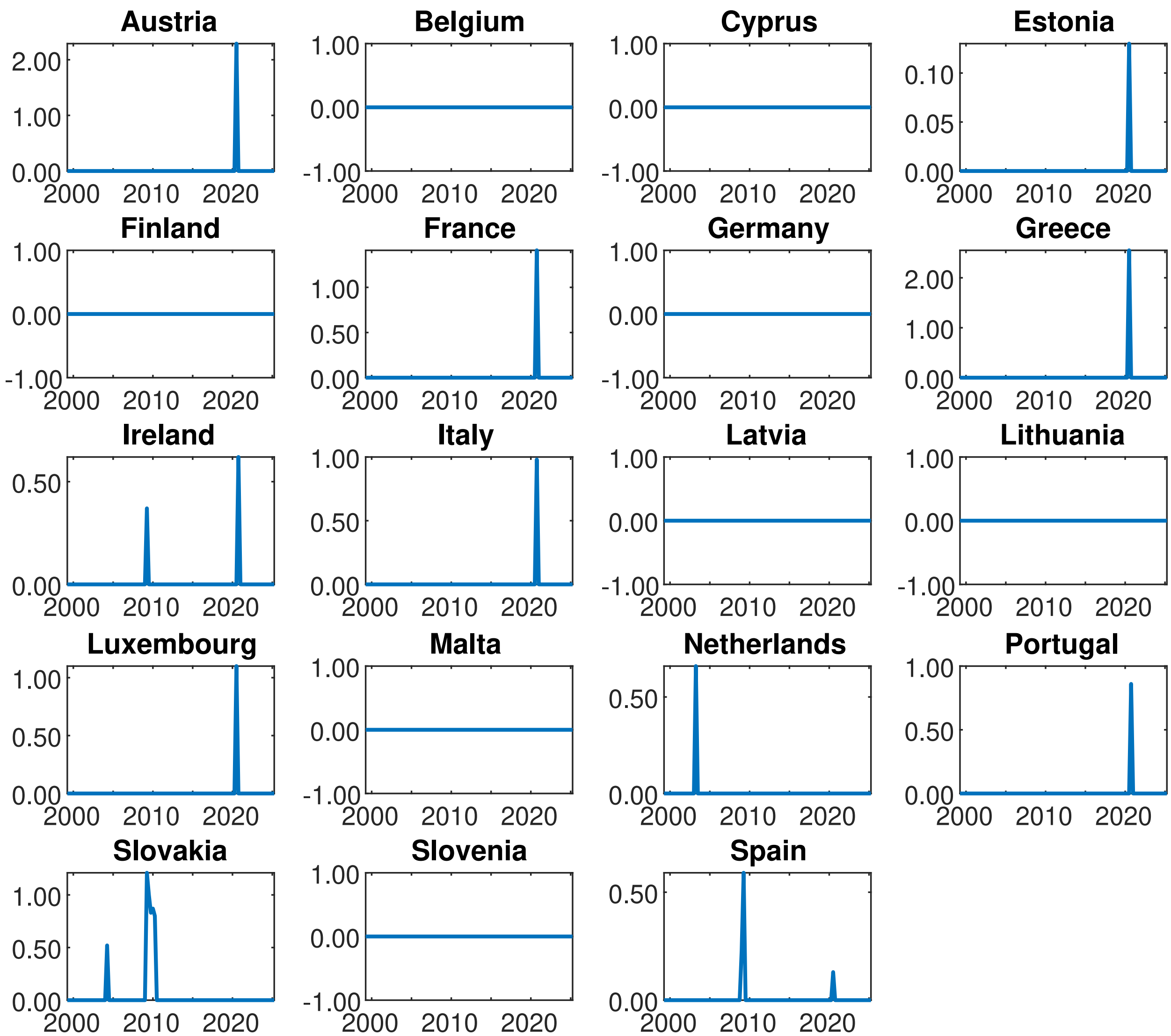


Figure C.3: Estimated unemployment rate change outliers (percentage points)



D Prior distributions

Tables D.1, D.2 and D.3 present the prior distributions and their hyper parameters across countries and the Eurozone common component. Our strategy to choose prior distribution hyperparameters is as follows: First, we estimate a model similar to that laid out in this paper, with the same observable variables, for the aggregate Eurozone data and for each country in Eurozone-19. This exercise helps us obtain weighted average measures for the common components of (i) the level of potential output, y^*, (ii) the trend growth rate of potential output, μ^y (iii) the natural unemployment rate, u^*, (iv) the trend change of the natural unemployment rate, μ^u, (iii) the inflation trend, π^*, (iv) the natural rate of interest, r^*, and (v) the output gap, c, using GDP weights. With these time series, we estimate the variances of their shocks and the persistence coefficients ϕ_1 and ϕ_2 of the cycle. We fix the variances of the shocks to those estimates and set the prior means of ϕ_1 and ϕ_2 to their respective estimates. In addition, we set the prior means of the initial values of these processes to the initial values of the weighted averages. Regarding the prior means of the monetary policy rule coefficients, we choose values close that are between those usual in the literature of estimated Taylor rules and those obtained from the estimation with aggregate Eurozone data. Finally, the parameter relating the shocks to r^* with those of μ^y is set in the vicinity of the posterior mean obtained with aggregate data. These choices appear in table D.3.

Moving to the country-specific coefficients in tables D.1 and D.2, the parameters of the cycle (ϕ_1, ϕ_2, λ_1, λ_2, γ_1, and γ_2), those of the Okun's law relationship (θ_1 and θ_2), and those of the Phillips curve relationship (β and κ) come from a combination of usual estimates in the literature and those obtained from estimations at the individual country levels. In addition, we set the the prior means of the loading coefficients ($\delta_i^y, \delta_i^c, \delta_i^u, \delta_i^\pi, \delta_i^r$) at one, as there is no prior information about these coefficients, and we assume in the prior distribution that all of the countries load equally on the common component.

Once we have (unit) prior means for the loading coefficients, we obtain the prior means of the coefficients of the idiosyncratic processes (μ_i^y, $\sigma^2_{\xi_i^y}$, μ_i^u, $\sigma^2_{\xi_i^u}$, ρ_i^π, $\sigma^2_{\xi_i^\pi}$, ρ_i^r, $\sigma^2_{\xi_i^r}$) by regressing the estimates of the latent variables obtained from the individual country estimations against the common components obtained as described above. Finally, we set the prior means of the initial values of the latent variables ($\pi^*_{0,i}, r^*_{0,i}, p^{10}_{0,i}$) at the posterior means obtained from the estimation of the individual country model.

Table D.1: Prior Distributions and Posterior Means for Countries Set 1

	Prior Distribution	Austria	Belgium	Cyprus	Estonia	Finland	France	Germany	Greece	Ireland	Italy
ϕ_1	$N(1.5,\ 1)$	0.92	0.94	1.24	1.79	0.50	0.78	1.80	0.94	0.87	0.69
ϕ_2	$N(-0.6,\ 1)$	-0.16	-0.20	-0.36	-0.84	0.12	0.09	-0.83	-0.04	-0.04	0.07
λ_1	$N(-0.1,\ 0.2)$	0.01	-0.04	-0.05	-0.01	-0.06	-0.09	-0.01	-0.12	-0.19	-0.08
λ_2	$N(-0.1,\ 0.2)$	-0.16	-0.11	-0.01	-0.00	-0.13	-0.02	-0.01	-0.02	-0.13	-0.07
γ_1	$N(-0.1,\ 0.2)$	-0.17	-0.06	-0.19	0.17	-0.14	-0.03	-0.03	-0.23	-0.22	-0.29
γ_2	$N(-0.1,\ 0.2)$	-0.18	-0.09	-0.09	-0.20	-0.14	-0.09	-0.07	0.01	0.04	-0.07
θ_1	$N(-0.25,\ 0.25)$	-0.24	-0.16	-0.10	-0.26	-0.21	-0.19	-0.26	-0.41	-0.32	-0.11
θ_2	$N(-0.25,\ 0.25)$	-0.12	-0.22	-0.17	-0.39	-0.27	-0.21	-0.25	-0.08	-0.28	-0.08
β	$N(0.8,\ 0.2)$	0.42	0.52	0.10	0.70	0.30	0.33	0.34	0.34	0.32	0.18
κ	$N(0.1,\ 0.2)$	0.33	0.27	0.15	0.12	0.40	0.33	0.05	0.10	0.40	0.21
ψ_1	$N(1.5,\ 1)$	1.11	1.10	1.25	1.31	1.10	0.93	1.17	1.56	1.52	1.07
ψ_2	$N(-0.6,\ 1)$	-0.16	-0.18	-0.33	-0.40	-0.18	-0.11	-0.21	-0.60	-0.58	-0.16
δ^y	$N(1,\ 2)$	0.95	0.82	0.78	1.11	1.15	0.84	0.77	1.12	1.19	1.05
δ^c	$N(1,\ 2)$	3.94	2.83	8.78	0.06	2.94	3.00	0.22	6.64	2.37	5.63
δ^u	$N(1,\ 2)$	0.18	0.32	0.84	0.62	0.33	0.21	0.11	0.52	0.73	0.39
δ^π	$N(1,\ 2)$	0.99	1.01	0.89	1.10	1.00	1.00	0.99	1.01	1.03	1.01
δ^r	$N(1,\ 2)$	1.66	1.66	1.84	7.08	1.99	1.98	1.34	1.72	1.97	2.03
ρ^π	$N(\bar{\rho}^\pi_i,\ 0.1)$	0.82	0.84	0.90	0.91	0.76	0.83	0.80	0.63	0.55	0.71
ρ^r	$N(\bar{\rho}^r_i,\ 0.1)$	0.92	0.92	0.90	0.91	0.92	0.90	0.92	0.91	0.92	0.92
μ^y	$N(\bar{\mu}^y_i,\ \bar{\mu}^y_i)$	0.01	0.12	0.47	0.50	-0.05	0.01	-0.02	-0.20	0.64	-0.23
μ^u	$N(\bar{\mu}^u_i,\ \bar{\mu}^u_i)$	0.02	0.00	0.06	-0.06	0.01	-0.00	-0.04	0.03	0.02	-0.03
σ^2_υ	IG(0.01, Inf)	0.09^2	0.16^2	0.09^2	0.09^2	0.08^2	0.06^2	0.04^2	0.11^2	0.08^2	0.06^2
$\sigma^2_{\varepsilon^\pi}$	IG(1, Inf)	1.00^2	0.73^2	2.25^2	2.14^2	0.93^2	0.67^2	1.37^2	1.30^2	1.64^2	0.97^2
$\sigma^2_{\eta^{p10}}$	IG(0.01, Inf)	0.10^2	0.10^2	0.10^2	0.10^2	0.57^2	1.24^2	0.10^2	0.16^2	0.10^2	0.28^2
$\sigma^2_{\varepsilon^{10}}$	IG(1, Inf)	0.28^2	0.29^2	0.48^2	0.79^2	0.32^2	0.41^2	0.30^2	0.94^2	0.38^2	0.35^2
$\sigma^2_{\xi^y}$	IG($\bar{\sigma}^2_{\xi^y_i}$, Inf)	0.61^2	0.33^2	0.95^2	1.01^2	0.75^2	0.37^2	0.57^2	1.13^2	2.48^2	0.41^2
$\sigma^2_{\varepsilon^\upsilon}$	IG($\bar{\sigma}^2_{\varepsilon^\upsilon_i}$, Inf)	0.19^2	0.13^2	0.53^2	0.36^2	0.12^2	0.13^2	0.16^2	0.56^2	0.18^2	0.13^2
$\sigma^2_{\xi^u}$	IG($\bar{\sigma}^2_{\xi^u_i}$, Inf)	0.27^2	0.29^2	0.41^2	0.63^2	0.27^2	0.19^2	0.11^2	0.38^2	0.39^2	0.26^2
$\sigma^2_{\xi^\pi}$	IG($\bar{\sigma}^2_{\xi^\pi_i}$, Inf)	0.00^2	0.00^2	0.01^2	0.01^2	0.00^2	0.00^2	0.00^2	0.00^2	0.00^2	0.00^2
$\sigma^2_{\xi^r}$	IG($\bar{\sigma}^2_{\xi^r_i}$, Inf)	0.05^2	0.05^2	0.13^2	0.16^2	0.05^2	0.04^2	0.06^2	0.60^2	0.09^2	0.08^2
π^*_0	$N(\bar{\pi}^*_{0,i},\ 0.5)$	1.82	1.85	1.63	2.02	1.83	1.82	1.81	1.85	1.89	1.84
r^*_0	$N(\bar{r}^*_{0,i},\ 0.5)$	1.97	1.97	2.18	8.41	2.36	2.35	1.59	2.05	2.34	2.41
p^{10}_0	$N(\bar{p}^{10}_{0,i},\ 0.5)$	1.57	1.61	3.10	6.38	2.04	3.81	1.31	3.90	2.01	2.35

Note: $N(\mu, \sigma)$ denotes a Normal distribution with mean μ and standard deviation σ, while $IG(\mu, \sigma)$ denotes an inverse-gamma distribution with mean μ and standard deviation σ.

Table D.2: Prior Distributions and Posterior Means for Countries Set 2

	Prior Distribution	Latvia	Lithuania	Luxembourg	Malta	Netherlands	Portugal	Slovakia	Slovenia	Spain
ϕ_1	$N(1.5, 1)$	1.67	1.63	1.20	0.46	0.61	0.49	1.76	-0.23	1.29
ϕ_2	$N(-0.6, 1)$	-0.75	-0.69	-0.47	-0.24	-0.20	0.09	-0.77	0.06	-0.35
λ_1	$N(-0.1, 0.2)$	0.01	-0.02	-0.05	-0.08	-0.03	-0.10	-0.01	-0.10	-0.03
λ_2	$N(-0.1, 0.2)$	-0.08	0.01	-0.13	-0.08	-0.03	-0.04	-0.00	-0.05	-0.01
γ_1	$N(-0.1, 0.2)$	-0.18	-0.13	-0.09	-0.20	-0.14	-0.12	-0.09	-0.08	-0.22
γ_2	$N(-0.1, 0.2)$	0.09	0.06	-0.03	-0.09	-0.19	-0.19	-0.07	-0.13	-0.14
θ_1	$N(-0.25, 0.25)$	-0.29	-0.57	-0.27	-0.16	-0.13	-0.15	-0.23	-0.14	-0.41
θ_2	$N(-0.25, 0.25)$	-0.23	-0.30	-0.10	-0.24	-0.13	-0.22	-0.21	-0.14	-0.21
β	$N(0.8, 0.2)$	0.44	0.65	0.34	0.26	0.36	0.17	0.85	0.48	0.26
κ	$N(0.1, 0.2)$	0.30	0.22	0.21	0.33	0.26	0.29	0.01	0.38	0.14
ψ_1	$N(1.5, 1)$	1.42	1.32	1.18	1.08	1.19	1.57	0.87	1.08	1.12
ψ_2	$N(1.5, 1)$	-0.48	-0.51	-0.23	-0.23	-0.24	-0.63	0.04	-0.17	-0.19
δ^y	$N(1, 2)$	1.64	0.79	1.44	0.54	0.91	0.97	0.37	1.61	0.78
δ^c	$N(1, 2)$	0.65	0.05	3.56	2.51	5.07	4.78	0.05	4.10	5.67
δ^u	$N(1, 2)$	0.49	0.45	0.06	0.16	0.34	0.63	0.51	0.47	0.75
δ^π	$N(1, 2)$	1.04	1.15	1.01	0.98	1.00	1.04	0.96	1.21	1.01
δ^r	$N(1, 2)$	2.20	2.96	1.78	1.90	1.39	1.87	2.56	2.79	2.08
ρ^π	$N(\bar\rho_i^\pi, 0.1)$	0.92	0.91	0.79	0.91	0.62	0.76	0.91	0.91	0.66
ρ^r	$N(\bar\rho_i^r, 0.1)$	0.91	0.91	0.91	0.90	0.93	0.91	0.84	0.91	0.93
μ^y	$N(\bar\mu_i^y, \bar\mu_i^y)$	0.19	0.70	0.10	0.96	0.06	-0.09	0.60	0.02	0.18
μ^u	$N(\bar\mu_i^u, \bar\mu_i^u)$	-0.05	-0.05	0.04	-0.03	0.02	0.04	-0.07	-0.00	0.01
σ^2_v	IG(0.01, Inf)	0.10^2	0.09^2	0.05^2	0.09^2	0.05^2	0.07^2	0.06^2	0.11^2	0.07^2
$\sigma^2_{\varepsilon^\pi}$	IG(1, Inf)	2.21^2	2.15^2	0.76^2	2.10^2	1.23^2	1.90^2	1.77^2	2.08^2	1.04^2
$\sigma^2_{\eta^{p10}}$	IG(0.01, Inf)	0.10^2	0.11^2	0.10^2	0.10^2	0.10^2	0.10^2	0.10^2	0.10^2	0.52^2
$\sigma^2_{\varepsilon^{10}}$	IG(1, Inf)	0.59^2	0.85^2	0.30^2	0.31^2	0.29^2	0.45^2	0.37^2	0.44^2	0.34^2
$\sigma^2_{\xi^y}$	IG($\bar\sigma^2_{\xi^y_i}$, Inf)	1.37^2	0.88^2	1.40^2	1.71^2	0.45^2	0.76^2	0.49^2	0.74^2	0.41^2
$\sigma^2_{\varepsilon^v}$	IG($\bar\sigma^2_{\varepsilon^v_i}$, Inf)	0.62^2	0.32^2	0.26^2	0.28^2	0.11^2	0.28^2	0.17^2	0.19^2	0.21^2
$\sigma^2_{\xi^u}$	IG($\bar\sigma^2_{\xi^u_i}$, Inf)	0.59^2	0.51^2	0.17^2	0.32^2	0.20^2	0.32^2	0.30^2	0.31^2	0.33^2
$\sigma^2_{\xi^\pi}$	IG($\bar\sigma^2_{\xi^\pi_i}$, Inf)	0.01^2	0.01^2	0.00^2	0.01^2	0.00^2	0.00^2	0.01^2	0.01^2	0.00^2
$\sigma^2_{\xi^r}$	IG($\bar\sigma^2_{\xi^r_i}$, Inf)	0.14^2	0.23^2	0.05^2	0.07^2	0.04^2	0.09^2	0.12^2	0.10^2	0.08^2
π_0^*	$N(\bar\pi^*_{0,i}, 0.5)$	1.91	2.10	1.84	1.80	1.84	1.90	1.75	2.22	1.84
r_0^*	$N(\bar r^*_{0,i}, 0.5)$	2.60	3.51	2.11	2.26	1.65	2.22	3.04	3.30	2.47
p_0^{10}	$N(\bar p^{10}_{0,i}, 0.5)$	3.38	2.81	1.40	2.32	1.67	2.66	3.32	2.99	2.61

Note: $N(\mu, \sigma)$ denotes a Normal distribution with mean μ and standard deviation σ, while $IG(\mu, \sigma)$ denotes an inverse-gamma distribution with mean μ and standard deviation σ.

Table D.3: Prior Distributions and Posterior Means for Common Eurozone Component

	Prior Distribution	Common
ϕ_1	$N(1.67, 1)$	1.49
ϕ_2	$N(-0.77, 1)$	-0.54
ρ^R	$N(0.8, 0.2)$	0.85
α_π	$N(1.5, 0.5)$	1.32
α_y	$N(1, 0.5)$	0.49
ω	$N(0.8, 0.4)$	0.70
$\sigma^2_{\eta^{y*}}$	0.13	—
$\sigma^2_{\eta^{\mu y}}$	0.00	—
$\sigma^2_{\epsilon^c}$	0.05	—
$\sigma^2_{\eta^{u*}}$	0.14	—
$\sigma^2_{\eta^{\mu u}}$	0.00	—
$\sigma^2_{\eta^{\pi*}}$	0.00	—
$\sigma^2_{\eta^{r*}}$	0.02	—
$\sigma^2_{\nu^{r*}}$	0.02	—
σ^2_e	IG(0.01, Inf)	0.03^2
$\sigma^2_{\epsilon^R}$	IG(1, Inf)	0.37^2
μ^y_0	$N(0.57, 1)$	0.60
μ^u_0	$N(-0.11, 1)$	-0.04
π^*_0	$N(1.82, 1)$	1.83
r^*_0	$N(1.95, 1)$	1.19

Note: $N(\mu, \sigma)$ denotes a Normal distribution with mean μ and standard deviation σ, while $IG(\mu, \sigma)$ denotes an inverse-gamma distribution with mean μ and standard deviation σ.

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