Banc Ceannais na hÉireann
Central Bank of Ireland
Eurosystem

Research Technical Paper

Understanding the Joint Dynamics of Inflation and Wage Growth in the Euro Area

Vahagn Galstyan

Vol. 2023, No. 11

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Vahagn Galstyan†

Central Bank of Ireland

December 13, 2023

Abstract

This paper presents an empirical framework and analysis of the interactions among inflation, wages, employment, and output in the euro area. Results identify price shocks and demand shocks as the primary exogenous factors explaining historical variance. The wage gap emerges as a key determinant of wage dynamics in the aftermath of a price shock. In contrast, the output gap becomes dominant following demand shocks. The real wage gap acts as a corrective mechanism, ensuring that prices and wages in particular align with the broader economic landscape. Forecasts for the period starting 2023Q3 emphasise the enduring significance of the real wage gap, projecting its ongoing impact on nominal wages in tight labour markets. As for inflation expectations, the estimates emphasise their stickiness. In this context, the significant and persistent price shock that has occurred suggests a gradual decline in expectations, potentially leading to an extended period of elevated inflation.

Keywords: Inflation, Wages, Central Banking

JEL classification: E00, E12, E30, E31, E32, E37

*I thank Philip Lane and Reamon Lydon for invaluable comments and suggestions. Aurelio Nocera provided excellent research assistance. The views expressed in this paper are personal and do not represent the views of the Central Bank of Ireland.

†Email: vahagn.galstyan@centralbank.ie

1. Introduction

In recent years, inflation has surged globally. The euro area, in particular, witnessed an annualised price growth of 10.6 percent in October 2022, a significant jump from near-zero levels recorded just two years prior. Such sharp inflationary pressures erode purchasing power, amplify economic uncertainty, and undermine overall economic performance and stability. Given the considerable costs of high inflation, understanding its underlying dynamics through empirical analyses becomes imperative. This paper contributes to the ongoing discourse on inflationary dynamics by examining the factors that influence inflation and wages in the euro area.

Drawing insights from the New Keynesian theory and setting aside its inherent cross-parameter constraints, it offers an empirical framework that models both the demand and supply in the goods market, and in the labour market. In terms of timeframe, the paper primarily concentrates on medium-run cyclical patterns, but achieving this requires modelling both short-run and long-run fluctuations. In essence, this research offers a comprehensive empirical framework that delves into the interrelationships among inflation, wages, employment, and output. The adopted approach maintains theoretical rigour yet provides the flexibility to understand the intricate links between the key macroeconomic variables.

With a primary emphasis on empirical analysis, this paper draws its theoretical underpinnings from the logical constructs found in New Keynesian models. Central to these models is the Phillips curve, an equation that ties current inflation to expected inflation and an indicator of economic slack (Woodford, 2003).[1] Various theoretical frameworks have been put forward for inflation modelling. For example, Calvo (1983) introduced a time-dependent approach, whereas Gertler and Leahy (2008) proposed a state-dependent one. Mankiw and Reis (2002) suggested a model considering information costs, and Gabaix (2020) advanced a behavioural New Keynesian framework. At a higher level, the logic of economic relationships is mostly similar across various models.

For the purposes of logical simplicity, this paper specifically adopts the framework detailed by Galí (2015).[2] Thus, the current framework is composed of four essential equa-

[1] Refer to Eser et al. (2020) for a discussion about the role of the Phillips curve in assessing the economic outlook and shaping monetary policy at the ECB.

[2] See Chapter 7.

tions. The first equation links inflation to inflation expectations, the deviation of medium-run output from its long-run trend, and a term representing error correction through the real wage gap. The second equation relates the growth rate of nominal wages to inflation expectations, labor market slack, and the real wage gap, which again serves to capture dynamics driven by error correction. The third equation describes aggregate demand as a function of both current and expected inflation. The fourth is a version of Okun's law. Notably, all the mentioned variables are latent. Within this structure, wage growth and inflation emerge as the pivotal variables of interest.

A resurgence of inflation in 2021 has reignited efforts to understand its underlying factors. Focusing on the euro area, Lane (2022) delves into the challenges of predicting medium-run inflation trajectories, especially against the backdrop of rising inflation combined with continual external shocks. He singles out the mid-2021 relative price disturbances as major influencers of the inflationary surge, further exacerbated by wage and price rigidities which led to a noticeable uptick in the inflation rate.[3] For the U.S., Bernanke and Blanchard (2023) employ a partial-equilibrium dynamic empirical model, dissecting the relationship between prices, wages, and inflation expectations. They use the ratio of job vacancies to the number of unemployed as an indicator of economic slack, aiming to understand the effects of both product-market and labor-market shocks in the U.S. during the pandemic. Their findings attribute the U.S. inflation spike in 2021 primarily to price shocks, with a particular emphasis on commodities.[4]

Currently, the authors are using their macroeconomic framework to extend their analysis to other major economies, including the euro area. The effort led by Bernanke and Blanchard, aligns with the broader effort in the policy circles. The strategy review initiated by the ECB in 2021 underscored the urgency for a comprehensive and renewed approach to macroeconomic modelling. In light of this, the current paper aims to fill the gap between the general equilibrium theory and the corresponding empirical modelling of economic relations. It is formulated within an empirical general equilibrium framework, borrowing its logical structure from the New Keynesian model, while setting aside inherent cross-parameter constraints.

Summarising the findings, the shock decomposition reveals that price shocks and

[3]This perspective is also echoed in several speeches about the recent surge in euro area inflation by the ECB executive board, available on the ECB website.

[4]Refer to Appendix A for some details on Bernanke and Blanchard (2023).

shocks to aggregate demand are the principal exogenous factors explaining historical variance. This is further enriched by the factor decomposition. Between 2019Q1 and mid-2021, the euro area experienced shifts in inflation dynamics, with the COVID-19 pandemic creating significant disruptions in 2020. While the labour market was robust pre-pandemic, supporting wage growth, the onset of COVID-19 suppressed wages and output. By 2023Q2, a synergy of price shocks, rising inflation expectations, a rebounding output gap, and labour market recovery pushed inflation and wage growth beyond their pre-pandemic levels.

The impulse response analysis reveals that in response to a price shock, an immediate rise in inflation results in a comparable negative real wage gap, spurring employment. However, elevated inflation contracts aggregate demand. As the effects of the initial shock diminish, inflation remains persistent due to the rise in inflation expectations. On the other hand, a demand shock prompts a positive output gap, subsequently raising inflation and labour demand. Both shocks exhibit a gradual return of variables to their steady-state values, with distinct pathways of adjustment and varying factor contributions. Importantly, the findings emphasise the role of the wage gap in shaping wage dynamics after a price shock, while the output gap is dominant in reactions to a demand shock.

Using the empirical framework for projections of key economic variables from 2023Q3 onwards, the output gap at the beginning of the forecast is approximately 2.5 percent, signalling overheating. The employment gap starts at 2.3 percent, indicating a tightness in the labour market. This is largely attributed to the positive output gap and the negative real wage gap. The real wage gap is projected to gradually revert to its steady-state value, starting from negative 0.5 percent at the beginning of the forecast horizon.

In relation to inflation and wages, the 2023 annual inflation rate is expected to be 5.3 percent. It is influenced primarily by inflation expectations, followed by the persistence of the price shock and a positive output gap. The estimates emphasise the significant stickiness of inflation expectations. Given the pronounced and enduring price shock observed, this suggests a gradual decline in expectations, potentially leading to an extended period of elevated inflation, with mean predictions for 2024, 2025, and 2026 at 4.1, 3.2, and 2.6 percent respectively. Meanwhile, wage growth for 2023 is projected to be 5.4 percent. For 2024, 2025, and 2026, forecasts are 4.5, 3.7, and 3.1 percent, respectively. The dynamics of adjustment are driven largely by the corrective effects of the real wage gap and labour market tightness, with inflationary expectations also playing a role.[5]

The paper is organised as follows. Section 2 provides a brief literature review. Section 3 introduces the data. Section 4 provides details on the empirical specification. Section 5 discusses the selection of priors. Section 6 presents the results for estimated parameters and extracted medium-run trends. Section 7 delves into a discussion on various decompositions. Section 8 covers the analysis of impulse responses. Section 9 offers out-of-sample projections for the main variables, and Section 10 concludes.

2. On Literature

2.1. A brief review

With the rise in inflation, a discussion on wage-price spirals is gaining momentum. Lorenzoni and Werning (2023) offer a perspective on inflation dynamics where disagreements between firms and workers about the relative price of labor and goods result in an inflationary spiral, with the disagreement tied to the magnitude of the output gap. They find that diverse shocks can lead to varying inflationary pressures in goods and labor markets, influencing the direction of real wages, but this movement is not a clear indication of the potency of the wage-price spiral.

Looking more closely at the importance of expectations in the Phillips curve, Werning (2022) provides an extensive discussion of how inflation expectations influence current inflation. Covering the main canonical firm-pricing models, he computes the pass-through and shows how it can vary across the models, and is not necessarily close to one, as is common in Calvo-type literature. He also finds that the timeframe matters, as long-run inflation expectations have less of an effect on current inflation. Instead, it is near-term expectations that play a dominant role.

Turning to non-linearities, Benigno and Eggertsson (2023) identify a non-linear rela-

[5]Data used for the initial projections includes information up to and including 2023Q2, downloaded on 15/09/2023. The release of 2023Q3 data in December, which indicated a notable decline in headline inflation, prompted a re-estimation of the model. The re-estimated parameters show no significant deviation from earlier estimates. The revised year-on-year average inflation projections for 2023-2026 are now 4.9, 3.5, 2.8, and 2.4 percent, respectively, with quarter-on-quarter projections at 4.5, 3.2, 2.6, and 2.3 percent. For wages, updated year-on-year growth projections for the same period are 5.3, 4.1, 3.3, and 2.9 percent, with quarter-on-quarter projections of 4.9, 3.7, 3.1, and 2.8 percent.

tionship between inflation and the ratio of job vacancies to the number of unemployed individuals. Their theoretical model suggests that labor market tightness significantly influenced the U.S. inflation spike in the 2020s. This perspective aligns with the findings of Harding et al. (2023), who highlight the role of the non-linear Phillips curve in explaining inflation trends after the Global Financial Crisis and during the post-pandemic period. Interestingly, these findings differ from those of Bernanke and Blanchard (2023), who find that a linear specification explains the post-pandemic surge in inflation quite well, and the 2021 U.S. inflation rise is primarily attributed to price shocks.

Shapiro (2022) introduces a framework that decomposes inflation into its supply-driven and demand-driven components. The findings indicate that demand-driven inflation typically decreases during recessions, while supply-driven inflation is often influenced by food and energy prices. Thus, tighter monetary policy leads to a reduction in demand-driven inflation, whereas oil-supply shocks elevate the supply-driven component of inflation. Applying this approach to the euro area, Gonçalves and Koester (2022) find that the rise in inflation in 2021 was initially driven by supply-side factors, including labor shortages, industrial goods constraints, and COVID-19 disruptions. However, as months progressed, demand factors, particularly from the recovering services sector, began to play a more prominent role in driving inflation.

Bobeica et al. (2019) examine the relationship between labor costs and price inflation in the euro area. They find that the interplay between prices and wages fluctuates based on economic conditions and types of shocks. Their findings reveal that labor costs are more likely to influence price inflation during demand shocks than supply shocks, with this effect being milder in low-inflation periods compared to high-inflation ones. In a related study, Hahn (2020) investigates the non-linear relationship between wages and prices in the euro area after the Global Financial Crisis. He finds that the response of prices to wages is markedly different between recessions and expansions, especially for demand shocks.

On the topic of energy prices, De Santis and Tornese (2023) provide evidence for non-linearities in the transmission of energy supply shocks, particularly in regimes characterised by high inflation. Their analysis reveals that energy shocks have a more pronounced impact on consumer prices during high-inflation periods, with the rapid transmission of these shocks to consumer prices (excluding energy), emphasising the significance of state-dependent responses. Continuing on the topic of global intermediaries, Hansen et al. (2023) highlight the pivotal roles of import prices and domestic profits in the recent surge of euro area inflation, noting that these factors contributed significantly to the change in the consumption deflator from 2022Q1 to 2023Q1.

2.2. Positioning within literature

> "...there is always a role for high-level frameworks
> that seek to predict medium-term inflation on the
> basis of a very small set of conditioning variables..."
> /Lane, 2022/

The ECB employs a diverse analytical toolbox consisting of various models. For baseline projections, the common choice is semi-structural models. Alternative scenarios often incorporate both semi-structural models and DSGEs. For short-term forecasting, the ECB frequently turns to time-series methods like factor models, BVARs, and error-correction models. ECB (2021) offers a comprehensive discussion on these models, highlighting their strengths, weaknesses, and areas for improvement. The current framework, to some extent, reflects the sentiment of the above quotation and can be seen as intermediate.

Secondly, a notable aspect that emerges from the literature is the interaction between wages, prices, and expectations (eg., Bernanke and Blanchard 2023; Lorenzoni and Werning, 2023). This theme is also echoed in the current paper, which emphasises the role of catch-up or correction via the real wage gap. Specifically, this research identifies the real wage gap as a crucial factor influencing wage dynamics in the euro area, particularly after a price shock. Addressing the topic of expectational pass-through, a preview of the results suggests that the estimated coefficient is significantly below one, somewhat resonating with Werning (2022).

Finally, the approach introduced in this paper is rooted in an empirical dynamic general equilibrium framework. This methodology complements both the theoretical discussions and the empirical findings mentioned above. For the sake of empirical tractability and simplicity, the paper adopts a linear approach, as opposed to non-linear papers (e.g., Benigno and Eggertsson, 2023).

3. Data

The empirical analysis requires quarterly data on inflation, and growth rates of wages, output and employment. All these variables are derived from data sourced from EUROSTAT.[6]

Both the CPI and the GDP deflator present unique advantages. The CPI tracks the prices consumers pay for a specific basket of goods and services, while the GDP deflator offers a broader perspective, capturing a wide range of domestically produced goods. Due to this expansive view, the GDP deflator is adept at reflecting the overall price movements of domestic goods. Notable studies, such as those by Ireland (2004) and Smets and Wouters (2007), used the GDP deflator to explore inflation dynamics over business cycles. As a result, the series for the GDP deflator index is used to construct the measure of inflation.[7]

Wages are measured using per-employee compensation, calculated from the ratio of employee compensation to the number of employees.[8] Data for total employment is used to calculate the growth rate of employment.[9] Chain-linked GDP in constant 2015 prices is used to measure the growth rate of output.[10]

The dataset, in terms of levels of the variables, spans from the first quarter of 1995 to the second quarter of 2023. This timeframe encompasses the COVID-19 era. In order to maintain this timeline while minimising the impact of extreme fluctuations during this period on the outcomes, a smoothing technique is applied to the variables. Specifically, for all variables measured in logarithmic differences, the Hodrick-Prescott filter with a smoothing parameter of one is applied between 2020Q1 and 2020Q3. These smoothed growth rates are then used to adjust the level observations, ensuring that the smoothing process does not alter the levels of the variables after the smoothing period. The differences in the logarithmic series form the final data covering the period from 1995Q2 to 2023Q2.

Table 1 presents summary statistics for the four key variables: inflation (π_t^p), nominal wage growth (π_t^w), employment growth (Δn_t), and real output growth (Δy_t). The sample

[6]The data were downloaded on 15/09/2023.
[7]Series code: "PD15_EUR,SCA,B1GQ,EA19".
[8]Series codes: "CP_MEUR,SCA,D1,EA19" and "THS_PER,SCA,SAL_DC,EA19".
[9]Series code: "THS_PER,SCA,EMP_DC,EA19".
[10]Series code: "CLV15_MEUR,SCA,B1GQ,EA19".

means of these variables stand at 0.46, 0.55, 0.21, and 0.36 respectively, paired with corresponding sample standard deviations of 0.36, 0.38, 0.32, and 0.73. The high standard deviations in growth rates of output and employment are predominantly attributable to the substantial contractions during the Global Financial Crisis and the euro area debt crisis. Towards the end of the sample period, all variables display pronounced volatility, largely due to the impact of the COVID-19 pandemic.

4. An Empirical Framework

4.1. On temporal dimension

The system comprises both observable and unobservable variables. Each variable exists across various time dimensions. Figure 1 offers a diagrammatic representation of the time horizon for a generic variable x_t. This horizon categorises economic timeframes into steady state, long run, medium run, and short run.

From the bottom of the figure, the steady state can be considered a specific subset of the long run, but devoid of perturbations. In such a setting, growth rates for all variables remain constant. The value of a variable in steady state is denoted with a bar over the variable and lacks a time subscript. With inflation being a policy variable, and in alignment with the ECB objective, its value in steady state is set at 0.5 percent (2 percent annualised). Furthermore, in line with the neoclassical growth theory, the methodology presumes that, in steady state, both real wages and output per employee grow at an identical rate: $\Delta\bar{y} - \Delta\bar{n} = \Delta\bar{\varpi}$.

In the long run, nominal frictions are absent, and macroeconomic variables remain unaffected by shocks from the short and medium run. This is consistent with the classical dichotomy, suggesting that monetary policy does not exert its impact on real economic factors in this timeframe. Here, the long-run value of x_t is denoted by $\bar{x}_t$. In the long run, it is assumed that output, employment, and real wages follow a random walk with drift, where the drift terms across these three variables are constrained in a manner that, in the absence of shocks, the growth rates of these variables revert back to their steady state levels. Furthermore, it is assumed that a long-run relationship exists between output, employment, and real wages, which can deviate from linear trends. In particular, for

$\bar{x}_t \in (\bar{y}_t, \bar{\varpi}_t, \bar{n}_t)$ it is assumed that $\Delta\bar{x}_t = \mu^x + \kappa^x \chi_t$, where $\chi_t = \rho_\chi \chi_{t-1} + e_t^\chi$. In the long run, inflation remains fixed at $\bar{\pi}_t^p = \bar{\pi}^p = 0.5$. Long-run inflation expectations also align with the 0.5 benchmark, underscoring the directive role of monetary policy. The growth rate of nominal wages at this frequency is pinned down by the long-run inflation rate and the long-run growth rate of real wages: $\bar{\pi}_t^w = \Delta\bar{\varpi}_t + \bar{\pi}^p$.

Central to this paper is the medium run, where nominal frictions come into play and the classical dichotomy breaks. In the medium run, nominal shocks exert an impact on both nominal and real variables. As medium-run shocks exclude high-frequency disturbances, the medium-run trend provides a clearer representation of the dynamic trajectory of variables. Specifically, when discussing inflation, the concept of 'underlying inflation' emerges as a medium-run phenomenon, stripping away short-run volatility to uncover foundational, persistent price movements. Consequently, for monetary policy, the future interest rate path is shaped by the medium-run trajectory of inflation. For the purpose of modelling, the medium-run trend of variable x_t is denoted by $\tilde{x}_t$. In this timeframe, variables fluctuate around their long-run trend. For output, employment, and real wages, these fluctuations are denoted by a hat, and are refered to as the output gap, employment gap, and real wage gap. Mathematically, these gaps are defined by the following identities: $\hat{y}_t - \hat{y}_{t-1} = \Delta\tilde{y}_t - \Delta\bar{y}_t$, $\hat{n}_t - \hat{n}_{t-1} = \Delta\tilde{n}_t - \Delta\bar{n}_t$ and $\hat{\varpi}_t - \hat{\varpi}_{t-1} = \tilde{\pi}_t^w - \tilde{\pi}_t^p - \Delta\bar{\varpi}_t$. The rest of the system in the medium run is described in the following subsection.

In the short run, shocks can create significant volatility without impacting the medium-run trend of the variables. Given the limited relevance of this timeframe to the current paper, short-run fluctuations are modelled as statistical noise and represented by $\varepsilon_t^x = x_t - \tilde{x}_t$. Thus, fluctuations of the variable x_t around its steady state are additively decomposed as:

$$x_t - \bar{x} = (\bar{x}_t - \bar{x}) + (\tilde{x}_t - \bar{x}_t) + (x_t - \tilde{x}_t) \tag{1}$$

where the first bracket captures long-run fluctuations around the steady state, the second bracket captures medium-run fluctuations around the long-run trend, while the third bracket captures short-run fluctuations around the medium-run trend. Importantly, ε_t^x also captures the mis-measurement of variables present in the data, in addition to proxying short-run fluctuations.

4.2. Expectations

It is assumed that expectations are backward-looking ($E_{t-1}\tilde{\pi}_t^p$), and these are modelled with exponential smoothing.[11] In particular, for a generic random variable x_t, the corresponding smoothed variable $\check{x}_t$ is defined as the weighted average of $\check{x}_{t-1}$ and x_{t-1}, with $\check{x}_t = (1-\theta)\,\check{x}_{t-1} + \theta x_{t-1}$, where $\theta \in (0,1)$.

Backward substitution shows that the exponentially smoothed variable is a weighted average of past realisations of the random variable x_t, with $\check{x}_t = (1-\theta)\sum_{j=1}^{\infty}\theta^{j-1}x_{t-j}$. Additionally, expectations are adaptive, as past overshoot of x_t above expectations leads to an upward revision of expectations. In the case of price inflation in the medium run, the exponential smoothing implies the following relation:

$$E_{t-1}\tilde{\pi}_t^p = (1-\theta)\,E_{t-2}\tilde{\pi}_{t-1}^p + \theta\tilde{\pi}_{t-1}^p \tag{2}$$

Thus, expectations are modelled as a function of past data and do not incorporate survey-based measures, as for example in Bernanke and Blanchard (2023).

4.3. Goods market

The analysis adopts the standard New Keynesian logic, positing that medium-run inflation is determined by the output gap, the real wage gap, and expected inflation. Hence, the following empirical specification is adopted:

$$\tilde{\pi}_t^p - \bar{\pi}^p = \beta^p\left(E_{t-1}\tilde{\pi}_t^p - \bar{\pi}^p\right) + a_{p\Delta y}\Delta\hat{y}_t + a_{py}\hat{y}_{t-1} + a_{p\varpi}\hat{\varpi}_{t-1} + v_t^p \tag{3}$$

The equation is mostly standard, but allows for a lag structure, as expanding the difference allows for the output gap to enter the equation both contemporaneously and with a lag.[12] The difference serves a purpose: the output gap is a very low-frequency variable, and adding the difference brings it to a scale similar to inflation. Furthermore, the real wage gap is introduced with a lag as well. As the inflation Phillips curve effectively represents the supply curve for goods and services, v_t^p in this context can be interpreted as supply shocks that account for the residual variation of inflation. These shocks are

[11] For a link between exponential smoothing and state-space representation see Hyndman et al (2008).

[12] As a theoretical reference, in the canonical New Keynesian model outlined by Gali (2015) in Chapter 7, the inflation Phillips curve adopts the following form: $\pi_t^p = \beta E_t \pi_{t+1}^p + \lambda_{py}\hat{y}_t + \lambda_{p\varpi}\hat{\varpi}_t$.

assumed to follow a first-order autoregressive process.

While this relationship is rooted in the standard New Keynesian model, the focus is not on the constraints imposed by the structural parameters on aggregate elasticities, but rather on the logic of the relationship. Consistent with the rationale of the New Keynesian Phillips curve, higher demand results in the average mark-up falling short of its desired level, prompting firms to adjust prices upwards. Similarly, a larger real wage gap leads to a below-desired average mark-up, causing firms to increase prices. In addition to the economic logic of the New Keynesian model, from a statistical standpoint, the lagged real wage gap acts as an error-correction term, exerting upward pressure on inflation when the gap is positive.

Next, the demand for goods and services is modelled as follows:

$$\hat{y}_t = \rho_y \hat{y}_{t-1} - a_{yp} \left(\tilde{\pi}^p_t - \bar{\pi}^p \right) + a_{ye} \left(E_{t-1} \tilde{\pi}^p_t - \bar{\pi}^p \right) + v^y_t \tag{4}$$

The equation assumes that the output gap is a negative function of current inflation and a positive function of expected inflation. This specification contrasts with Bernanke and Blanchard (2023), who do not model domestic slack endogenously. This distinction is crucial because, in the medium run, output is highly susceptible to changes in inflationary pressures, either directly through demand as modelled in this paper, or indirectly via the monetary policy stance. The demand equation above stems from rewriting the real interest rate gap, using the Fisher identity and the following interest rate rule:[13]

$$i^p_t = r^n_t + \bar{\pi}^p + \frac{a_{yp}}{a_{ye}} \left(\tilde{\pi}^p_t - \bar{\pi}^p \right) + e^i_t$$

The assumed policy rule ensures that the natural rate does not affect the output gap, conditional on the interest rate rule. This is not inconsequential. Rules of other forms that do not neutralise the natural rate require the explicit modelling of the nominal interest rate.[14] In the euro area, over the sample period, the nominal interest rate primarily exhibits a downward trend. This poses challenges in estimation since the variable resembles a non-

[13] As a theoretical reference, in the canonical New Keynesian model described by Gali (2015) in Chapter 7, the corresponding equation takes the form: $\hat{y}_t = E_t \hat{y}_{t+1} - \lambda_{yr} \left(i_t - E_t \pi^p_{t+1} - \tilde{r}_t \right)$.

[14] Regarding interest rate smoothing, the nominal interest rate can be expressed as a function of medium-run inflation, noted for its stickiness. Given a rule of the form $i_t = \rho i_{t-1} + (1 - \rho)\pi_t$, where π_t represents current headline inflation, solving for i_t implies that interest rates depend on both current and past inflation rates. This is encapsulated by the concept of medium-run inflation.

stationary series. Importantly, the residual variation in aggregate demand is composed of exogenous shifts in monetary policy and other exogenous shifts in demand, which in the current specification cannot be distinguished. Finally, the composite error v_t^y follows a first-order autoregressive process.

4.4. Labour market

Moving on to wages, the growth rate of nominal wages is determined by expectations, as well as the employment gap. The use of employment instead of unemployment allows for accommodating features such as trends that are present in the data.[15] Thus the wage Phillips curve is specified as follows:

$$\tilde{\pi}_t^w - \bar{\pi}_t^w = \beta^w \left(E_{t-1}\tilde{\pi}_t^p - \bar{\pi}^p\right) + a_{w\Delta n}\Delta\hat{n}_t + a_{wn}\hat{n}_{t-1} - a_{w\varpi}\hat{\varpi}_{t-1} + v_t^w \tag{5}$$

where $\bar{\pi}_t^w = \Delta\bar{\varpi}_t + \bar{\pi}^p$ and $\hat{n}_t$ measures the employment gap.[16] Similar to the logic presented for equation (3), both the change in the employment gap and the lag of the employment gap are present in the equation. Additionally, the lag of the real wage gap is introduced to provide greater empirical flexibility.[17] It is important to note that in this specification, it is the expectation of price inflation that influences wage setting, diverging from the approach of using expectations of wage growth as presented by Gali (2015). This approach aligns with the empirical methodology adopted by Bernanke and Blanchard (2023). As before, v_t^w explains the residual variation of the wage inflation, and follows a first-order autoregressive process.

The wage equation effectively captures the labour supply curve. The relation states that a decline in labour demand, for a given level of labour supply, reduces employment. The resulting excess supply of labour causes wages to fall. Similarly, an increase in labour supply for a given level of labour demand results in higher unemployment and lower wages. From a statistical perspective, the lagged real wage gap functions as an error-

[15] Using the definition of the unemployment rate combined with the labor force, the employment level can be expressed as $N_t = (1 - u_t)L_t$. This indicates a negative correlation between the unemployment rate and the employment gap.

[16] For a theoretical reference, in the canonical New Keynesian model described by Gali (2015) in Chapter 7, the counterpart equation takes the form: $\pi_t^w = \beta E_t \pi_{t+1}^w - \lambda_{wu}\hat{u}_t$. The deviation from the canonical model involves using the employment gap instead of the unemployment rate gap, leading to a reversal of the sign on the relevant variables.

[17] For example, in the New Keynesian model described by Gali (2015) in Chapter 7, the real wage gap influences wages through labour demand only.

correction term, exerting upward pressure on wages when the gap is negative.

The next key equation links the employment gap to the output gap and the real wage gap, as well as its own lag:

$$\hat{n}_t = \rho_n \hat{n}_{t-1} + a_{ny}\hat{y}_t - a_{n\varpi}\hat{\varpi}_t + v_t^n \tag{6}$$

As the variables on the right-hand side are primarily slow-moving, in the current specification all factors on the right-hand side enter contemporaneously.[18] The equation suggests that a higher demand for goods and services results in a greater demand for labour, which, given a constant level of labour supply, increases the employment gap. Conversely, a larger real wage gap is positively associated with a higher labour supply. For a constant level of labour demand, this reduces the employment gap. As before, v_t^m explains the residual variation of the employment gap, and is modelled as a first-order autoregressive process.

Equations (2)-(6) together with the equations for variables in the long run and steady-state constraints form the system.

5. Selection of Priors

The system comprises 30 parameters that need to be estimated. It also includes 18 unobservable endogenous variables. Each of the four observable variables has 113 observations. Except for the steady-state inflation, which is fixed at 0.5, all other parameters are estimated. Given the structure of the empirical model, Bayesian estimation methods complemented by Kalman filtering techniques are essential. The approach adopted is primarily data driven due to limited prior knowledge about the magnitudes of the parameters, except for their signs.

[18]For a theoretical reference, in the canonical New Keynesian model described by Gali (2015) in chapter 7, the counterpart equation takes the form: $\hat{u}_t = -\lambda_{uy}\hat{y}_t + \lambda_{u\varpi}\hat{\varpi}_t$. The deviation from the canonical model involves using the employment gap instead of the unemployment rate gap, leading to a reversal of the sign on the relevant variables.

5.1. Shocks

To gain insights into the temporal dimension, $\ddot{x}_t$ is defined as the four-quarter moving average for $x_t \in (\pi_t^p, \pi_t^w, \Delta n_t, \Delta y_t)$, serving as the initial proxy for the medium-run trend.[19] It is important to emphasise that these are used solely for the initial estimation of the standard deviations of the short-run and medium-run shocks. They are not incorporated into system estimation as a medium-run trend. Next, within the framework of a state-space representation, an observation equation is defined as follows:

$$x_t = \ddot{x}_t + \varepsilon_t^x \tag{7}$$

where ε_t^x is unobservable and captures short-run fluctuations, and $\ddot{x}_t$ serves as a proxy for the medium-run trend. To obtain an initial estimate of the standard deviation for medium-run shocks, it is further assumed that:

$$\ddot{x}_t = \eta^x \ddot{x}_{t-1} + \tau_t^x \tag{8}$$

where τ_t^x is unobservable and follows a first-order autoregressive process with a disturbance denoted by e_t^x.[20] These two equations are estimated for each x_t. The results of the estimates of σ_{ε^x} and σ_{e^x} with their corresponding standard errors are shown in rows one and two of Table 2. A normal distribution with mean and standard deviation taken from the first row of the table serves as the priors for standard deviation of short-run shocks denoted by σ_{ε^x}.

The final row of the table presents the ratio $\sigma_{\varepsilon^x}/\sigma_{e^x}$ along with its associated standard error. Although there is no theoretical basis for this pattern, the ratio seems to remain relatively stable across the variables. Hence, the standard deviation of medium-run shocks are defined by $\sigma_{e^x} = \lambda\sigma_{\varepsilon^x}$, where $\lambda = \sum(\sigma_{\varepsilon^x}/\sigma_{e^x})/4$. The prior for the λ parameter is also set to a normal distribution with a mean of 2.6 (the arithmetic average of $\sigma_{\varepsilon^x}/\sigma_{e^x}$ across the four variables). Similarly, the prior value for the standard deviation of this distribution is derived from the arithmetic average of the standard errors across the four variables (0.3 in this case). This approach narrows the parameter space, facilitating the estimation

[19]Note that, at an annual frequency, this is equivalent to seven quarterly observations.

[20]The two equations can be estimated individually without the state-space representation. However, with the state-space representation, it is relatively easy to estimate the standard deviation of ε_t^x and e_t^x.

of 30 parameters instead of 33.

5.2. Elasticities

Turning to sensitivities, they are more likely to fall within the interval of 0 to 1. Using uniform priors is strongly discouraged, so curved priors are adopted instead (Gelman and Yao, 2021). Additionally, in modal estimation, it is crucial to eliminate the boundary problem. A Gamma prior appears suitable for this purpose. To determine the optimal generic parameterisation for the Gamma distribution, 100 million draws from a truncated $N \sim (0.5, 0.5)$ distribution are initially generated. Parameters of the Gamma distribution are then estimated based on this sample. The resulting estimates for the shape and scale parameters are 1.885 and 0.341, respectively. These parameters infer that the mean, standard deviation, and mode of the Gamma distribution are 0.644, 0.469, and 0.576, respectively. These values are set as priors across all elasticities that are not bounded between 0 and 1. Panel (a) of Figure 2 displays the shape of this distribution.[21]

For parameters bounded between 0 and 1, a similar approach is undertaken. Drawing from 100 million samples of a truncated $N \sim (0.5, 0.5)$ distribution, the parameters of a Beta distribution are then estimated to achieve the best representation. The resulting alpha and beta parameters for the Beta distribution are both estimated at 1.173. This yields a mean of 0.5 and a standard deviation of 0.273. These values are subsequently used as priors for this set of parameters. Panel (b) of Figure 2 displays the shape of this distribution.

5.3. Long-run growth

Finally, the long-run properties of the growth rate are extracted by using several low-frequency trigonometric weighted averages (Müller and Watson, 2015). In particular, the cosine projections are constructed as the fitted values obtained by regressing Δy_t onto a constant term and $\sqrt{2}\cos\left(j\left(t-0.5\right)/T\right)$ for $j = 1, ..., 12$. Next, using the resulting series, a simple ARIMA(1,0,0) is estimated to determine the standard deviation of the long-run growth rate of output, the persistence parameter of the process, and the associated standard errors. The point estimate for the standard deviation of the long-run growth rate of

[21] While the Gamma distribution is not constrained on the right, only the zero to one interval is plotted for clarity.

output stands at 0.049, with an associated standard error of 0.009 (statistically significant at 1 percent). These estimates serve as priors for σ_χ with $N \sim (0.049, 0.009)$. The estimated persistence parameter is 0.987 with a corresponding standard error of 0.006. These estimates are used as priors for ρ_χ with $N \sim (0.987, 0.006)$.

Throughout the estimation, all normal priors are truncated on the left. The estimation begins by finding the mode of the posterior distribution and then implementing the Metropolis-Hastings algorithm. A single chain is generated, consisting of 10 million draws, with an acceptance rate of 31 percent. After discarding the first 5 million draws, the convergence diagnostics signal convergence of the chain. The estimation procedure is executed using DYNARE (Adjemian et al., 2022).

6. Estimation Results

The data sample used for estimation is short, especially considering the number of parameters and unobservable variables that need to be estimated. In certain instances, some parameters are weakly identified. Further investigation is required to address these limitations. Nonetheless, both the impulse response functions and the historical shock decomposition seem reasonable, suggesting that the estimated parameters are largely plausible.

6.1. Parameters

Before examining the parameters of the medium-run system, it is instructive to consider the implications of the estimated parameters in the steady state.[22] The estimates imply the following steady-state patterns on an annual basis. The rate of economic expansion, measured by the growth rate of GDP, stands at $\Delta\bar{y} = 1.33$ percent, while the growth rate of employment is approximately $\Delta\bar{n} = 0.88$ percent. From these estimates, per-capita output growth rate in the steady state is deduced to be around $\Delta\bar{y} - \Delta\bar{n} = 0.45$ percent. Consequently, the growth rate of real wages is $\Delta\bar{\varpi} = 0.45$ percent. Inflation, gauged by the logarithmic change in the GDP deflator, is fixed at $\bar{\pi}^p = 2$ percent in the steady state. Based on these estimates, the steady-state growth rate of nominal wages is deduced to be $\bar{\pi}^w = 2.45$ percent.

[22] For conciseness, these estimates are not presented but are available upon request.

Table 3 displays the estimation results for the primary parameters of interest, grouped by equation. Interpreting the raw coefficients of dynamic models directly can be misleading (e.g., coefficients of a VAR model). This is because these models involve complex interrelationships between variables over time, and the coefficients simply capture a snapshot of those relationships at one point in time. In such models, the interpretation of coefficients as marginal effects (as in linear regression) does not hold. Instead, a more intuitive way to understand the dynamics of the model is through impulse response functions. Nevertheless, the text below provides an overview of estimated parameters, focusing on the values at mode and corresponding standard deviations.

The parameter θ quantifies the extent to which inflation expectations are revised. A value closer to one suggests a quicker adjustment of expectations. This parameter has an estimated value of roughly 0.53, accompanied by a standard deviation of 0.31. Such a coefficient highlights a significant role historical inflation plays in shaping expectations. For example, if past inflation exceeds prior expectations by a percentage point, inflationary expectations typically rise by approximately 53 basis points. The estimated parameter also suggests that contributions of past inflation to expectations become negligible after the first four quarters.

Regarding the inflation Phillips curve, coefficient β^p captures the responsiveness of inflation to its expectations. The estimated value is about 0.41, with a standard deviation of 0.34. The extent to which inflation correlates with the output gap is represented by the $a_{p\Delta y}$ and a_{py} parameters. The former shows how inflation reacts to immediate changes in the output gap, given a constant demand. With an estimate of 0.13 and a standard deviation of 0.07, this suggests that fluctuations in the output gap can notably influence inflation. On the other hand, a_{py}, which indicates how past output gaps affect current inflation, has an estimated value of 0.07 and a standard deviation of 0.06. This effect appears more muted, possibly due to inflation and the output gap having different amplitudes of movement.

Parameter $a_{p\varpi}$ shows the impact of the lagged real wage gap on inflation. In the current empirical framework, it can be used to interpret the correction of inflation towards its long-run value. For example, when the real wage gap is positive, the correction requires an increase in prices. The estimated value for this parameter is 0.13, coupled with a standard deviation of 0.14. Finally, the persistence of price shocks is estimated at 0.84 with a

0.12 standard deviation.

In the wage equation, coefficient β^w reflects wage sensitivity to expected inflation, estimated at 0.13 with a standard deviation of 0.27. The $a_{w\Delta n}$ parameter measures immediate wage response to changes in the employment gap, conditional of keeping the other factors fixed. Estimated at 1.23, with a standard deviation of 0.23, it suggests that employment gap variations can strongly impact wage growth. On the other hand, the a_{wn} parameter denoting the impact of past employment gaps on current wage growth, has an estimate of 0.14 and a standard deviation of 0.10. The two estimates suggest that fluctuations of medium-run employment around its long-run trend are more tightly linked to movements in wages, compared to the relationship between inflation and the output gap.

Similar to inflation, $a_{w\varpi}$ parameter measures error correction and indicates the required wage adjustment in light of deviations from long-run equilibrium. Its estimated value is 0.96 with a standard deviation of 0.09. The estimate is considerably higher than the one for inflation, and the standard deviation at the mode is much smaller, suggesting that error correction significantly influences euro area wage dynamics. Finally, the estimated persistence for wage shocks is quite small at 0.15, with a standard deviation of 0.34.

Turning to labour demand, the employment gap demonstrates moderate persistence, with an estimated parameter of 0.24 and a standard deviation of 0.19. The sensitivity of the employment gap to the output gap, represented by the coefficient a_{ny}, is estimated at 0.61 with a standard deviation of 0.14. Meanwhile, the sensitivity to the real wage gap, captured by the coefficient $a_{n\varpi}$, is estimated at 0.35, accompanied by a standard deviation of 0.23. Additionally, the persistence of labour demand shocks is estimated at 0.53 with a standard deviation of 0.60.

Lastly, aggregate demand demonstrates a high level of persistence, with a value of 0.80 and a standard deviation of 0.13. The persistence in demand is likely indicative of habit formation among consumers. The sensitivity of demand to current inflation, represented by a_{yp}, is estimated at 0.18 with a standard deviation of 0.19. Sensitivity to expected inflation, indicated by a_{ye}, stands at 0.21 with a standard deviation of 0.22. Demand shocks are also notably persistent, having a coefficient of 0.81 and a standard deviation of 0.11.

Table 4 summarises the results for the estimated standard deviations of short-run and medium-run shocks. The estimated standard deviations for short-run fluctuations in inflation, wages, employment, and output are, respectively, 0.20 (0.01), 0.22 (0.02), 0.11 (0.02), and 0.52 (0.04) - with standard errors in parentheses. The implied standard deviations for medium-run shocks for these variables can be determined by dividing the short-run standard deviation by the parameter λ. In the same order, these are 0.11, 0.12, 0.06, and 0.28.

6.2. Signal and noise

The blue line in Figure 3 represents the actual quarterly series, while the red line depicts the extracted medium-run trend for the four observed variables. Panel (a) presents the results for inflation. The derived medium-run trend is noticeably smoother, effectively reducing pronounced volatility. Panel (b) displays the results for wages. The medium-run trend for wages exhibits a slightly higher degree of volatility compared to inflation. This difference primarily arises from the modelling assumptions, where long-run nominal wage growth is determined by a mix of equilibrium long-run real wages and a steady-state level of inflation.

Both inflation and the growth rate of nominal wages display consistent patterns, with values nearing the steady-state levels before the Global Financial Crisis. After the crisis, both measures declined below their steady-state values, recovering gradually up to the onset of the COVID-19 shock. Following this event, both indicators register values that significantly surpass the steady state.

A somewhat similar pattern emerges for the growth rates of output and employment. The medium-run trend effectively filters out short-run fluctuations. Both series witnessed declines following the Global Financial Crisis and the COVID-19 shocks, with subsequent recoveries. The medium-run trends for both output and employment growth then display renewed momentum.

7. Decompositions

7.1. Variance decomposition

Table 5 provides the variance decomposition that sheds light on the contribution of different shocks to fluctuations in key economic variables. For inflation, the price shock is the predominant contributor, accounting for 56.8 percent of the variations. Following closely, the demand shock explains 43.0 percent, underscoring that exogenous shifts in aggregate demand significantly influence inflationary dynamics. Other shocks make a minor impact. Unsurprisingly, expected inflation is explained by the same shocks with somewhat similar contributions. Wage growth is also influenced primarily by the price shock at 47.5 percent, followed by the demand shock at 41.1 percent. The wage shock and labour demand shock play smaller roles, contributing 7.3 and 3.4 percent respectively.

When examining the output gap and employment gap, both variables are almost entirely shaped by exogenous shifts in aggregate demand, with large contributions of 99.9 and 99.1 percent respectively. The influences of other shocks on these variables are minimal. The real wage gap sees a more balanced influence from the demand shock and the price shock, contributing 46.8 and 43.3 percent respectively. This underscores the pivotal roles both shocks play in determining fluctuations in real wages.

Overall, the demand shock significantly influences the key economic variables. Conversely, the price shock emerges as the primary force behind inflation, wage growth and the real wage gap. Other shocks provide supplementary insights.

7.2. Shock decomposition

Figure 4 presents the results of the historical shock decomposition over the sample period. The subsequent text focuses on the more recent period from 2019Q1 to 2023Q2.

Panel (a) presents the decomposition for medium-run inflation. From 2019Q1 to 2019Q4, inflation hovered just below the ECB target. This period was marked by positive demand shocks counteracted by negative price shocks. Between 2020Q1 and 2020Q3, both types of shocks were negative, pushing medium-run inflation well below its steady state. Starting in 2020Q4, price shocks took hold, propelling medium-run inflation above the steady-state by 2021Q2. Subsequent to this, both price and demand shocks have been driving inflation upwards.

Panel (b) details the decomposition for the medium-run growth rate of nominal wages. Starting in 2019Q1, there was a declining trend in the wage growth, primarily attributed to price shocks. In 2020Q1, a sharp decline in wage growth occurred, largely influenced by demand shocks. From 2021Q2, a mix of positive price and demand shocks drove the growth rate of nominal wages notably above its steady state.

Panels (c) and (d) outline the decomposition for the output gap and the employment gap respectively. These gaps display highly similar patterns, mainly because the employment gap is substantially explained by the output gap. Both gaps are majorly influenced by shocks to aggregate demand. Between 2019Q1 and 2019Q4, demand shocks kept the gaps positive. However, the stretch from 2020Q1 to 2021Q1 was dominated by negative shocks, keeping both gaps negative. From 2021Q3 onwards, positive demand shocks have elevated both gaps above their pre-pandemic levels. Interestingly, while price shocks have slightly mitigated the output gap, they have contributed positively to the employment gap. This latter effect has been mediated by the real wage gap.

Panel (e) shows the decomposition for the real wage gap. Prior to the pandemic, the gap was predominantly positive, spurred by positive price and demand shocks. From 2019Q4 to 2020Q3, negative demand shocks shifted the gap to negative territory. Between 2021Q1 and 2022Q1, positive output shocks moved the gap back into positive territory. However, even though demand shocks remained positive thereafter, dynamics of the wage gap were predominantly influenced by significant price shocks, plunging the real wage gap into negative territory.

Finally, although the cyclical variation in GDP growth rate is primarily driven by medium-run shocks, the growth rate has consistently remained below the steady state since the Global Financial Crisis. This is mainly due to the below steady state growth rate of the long-run output (panel (f)).

While this analysis is informative, it does not provide deep insights into factor contributions. For example, the price shock impacts inflation, inflation expectations, and the wage gap. The current decomposition does not explain how each variable is associated with the dynamics of the primary variables under consideration. Consequently, a more detailed factor decomposition is presented below.

7.3. Factor decomposition

Figure 5 presents the results of the factor decomposition over the sample period. While the factor decomposition is informative, it is important to recognise that all factors are interrelated. The subsequent text focuses on the more recent period from 2019Q1 to 2023Q2.

Panel (a) shows the results of the decomposition for medium-run inflation. The period spanning from 2019Q1 to 2019Q4, was largely characterised by a positive output gap, positive real wage gap, and the gradual recovery of inflation expectations towards their steady-state value. These factors were somewhat counterbalanced by negative price shocks. As a result, inflation hovered slightly below its steady-state value, with annualised medium-run inflation reaching close to 2 percent in 2019Q4. The outbreak of the pandemic in 2020 brought about significant changes. In 2020Q1 and 2020Q2, a sharp contraction in aggregate demand and falling inflation expectations led inflation to dive below its steady-state value. From 2020Q4, notable price shocks arose. Along with rising inflation expectations and a positive output gap, inflation has moved well above its steady state.

Panel (b) shows the results of the decomposition for medium-run growth rate of nominal wages. During 2019, the labour market was tight, characterised by a positive employment gap. This had a favourable effect on wage growth, although the effect gradually diminished. When combined with the correction exerted on wages by the positive real wage gap, the trajectory of nominal wages trended downwards from its steady-state value. The pandemic then induced a sharp employment drop, which in turn suppressed wage growth. From 2021Q2 onwards, labour markets displayed signs of tightness and inflation expectations began to climb, both of which contributed to increasing wage growth. This upward trend was partially counteracted by the positive real wage gap that persisted from 2021Q3 to 2022Q2. From 2022Q3 onwards, the upward corrective pressure from the negative real wage gap, labour market tightness, and mounting inflation expectations have driven wage growth significantly above its steady-state level.

Panel (c) displays the decomposition of the output gap. In 2019, the economy was overheating, evidenced by a positive output gap of approximately 1.7 percent. The periods 2021Q1 and 2021Q2 experienced a significant shock due to the COVID-19 pandemic. This led to a decline in the output gap, pushing it into negative territory, where it lingered from 2020Q2 through to 2021Q1. As the economy began to recover from the pandemic, a series of positive demand shocks propelled the output gap back into positive territory from 2021Q2 onwards. Coupled with the significant own persistence, the output gap has now surpassed its pre-pandemic level, reaching a value of 2.7 percent in 2023Q2.

Panel (d) displays the results of the decomposition for the employment gap. The dynamics of the labour market, characterised by the employment gap, are intrinsically linked with those of aggregate demand, as represented by the output gap. From 2019Q1 to 2019Q4, a positive output gap applied upward pressure on labour demand. Yet, when the output gap contracted in 2020Q1, it resulted in diminished labour demand. This negative employment gap persisted throughout the 2020Q2-2021Q2 period. Starting in 2021Q3, labour demand began its recovery, and by 2023Q2, the labour market has become tighter than before the onset of the pandemic.

Panel (e) illustrates the decomposition of the real wage gap. By its design, inflation exerts downward pressure on the real wage gap, whereas growth in nominal wages tends to elevate it relative to the long-run trend. 2019 was characterised by a positive gap, signifying that real wages exceeded their long-run trend. Nevertheless, there was an overarching downward trend during this time. Between 2020Q1 and 2020Q3, the real wage gap declined into negative territory. It then remained close to its long-run equilibrium from 2020Q4 to 2021Q1 before climbing back into positive territory, peaking in 2021Q3. Since then, the trend of the real wage gap has been on a downward trajectory, turning negative in 2022Q2 and declining further. This negative wage gap is likely to necessitate an adjustment in both nominal wages and prices.

Panel (f) displays the results for the medium-run growth rate of the output. Since this decomposition stems from the output gap identity, the growth rate essentially represents the slope of the output gap in panel (c), conditional on the growth rate of long-run output. As mentioned earlier, beyond cyclical fluctuations, the medium-run growth rate has been below the steady-state level, primarily due to the sub-par long-term growth rate of the output.

8. Dynamic Analysis

The variance decomposition suggests that most of variation comes from price and demand shocks. Consequently, impulse response functions for only these two shocks are discussed in the paper.[23]

8.1. A price shock

Figure 6 illustrates the response of the main variables after a shock to e_t^p with a magnitude of $\bar{\pi}^p = 0.5$. As the shock enters the inflation equation, it instantly elevates inflation by approximately 0.5 percentage points, resulting in a nearly identical negative real wage gap. This negative real wage gap, in turn, boosts employment through the labour demand equation, as it enters the equation contemporaneously. Increased labour demand puts upward pressure on wages. At the same time, aggregate demand contracts due to the heightened inflation, which also enters the demand equation contemporaneously. These patterns are clearly observed in the first bar of each panel in the figure.

Following the initial shock, the variables begin a gradual adjustment back to their steady-state values. In panel (a), the persistence of the shock maintains inflation above its steady-state value for an extended duration. Even as the influence of the shock wanes, inflation expectations rise, sustaining inflationary momentum. Meanwhile, the negative real wage gap exerts a corrective pressure on these inflationary forces in the opposite direction. Contributions from the output gap are negligible.

Panel (b) displays the breakdown of the wage response. Following the initial shock, the corrective force stemming from the real wage gap accelerates the growth rate of nominal wages. An increase in inflation expectations also contributes to wage growth.

Panel (c) offers the breakdown for the output gap. After its initial dip, the persistent nature of the gap depresses aggregate demand. Elevated inflation tends to dampen demand, while inflation expectations have the opposite effect. After the initial shock, pressure on aggregate demand arising from contemporaneous inflation dominate pressure from expected inflation. Over time, however, these factors largely neutralise each other.

Panel (d) depicts the employment response. The dynamics here are chiefly governed

[23]The remaining responses are available from the author upon request.

by the real wage gap. Since a negative real wage gap corresponds to diminished labour supply for a given labour demand, it raises the employment gap. Meanwhile, a decline in aggregate demand, and the associated reduction in labour demand, works to narrow the employment gap. Nevertheless, this latter effect is insufficient to counterbalance the forces arising from the real wage gap.

Panel (e) presents findings related to the real wage gap. This decomposition hinges on the real wage gap identity. After its initial decline, the decomposition reveals that the initial dominance of inflation recedes after the first few quarters. The subsequent dynamics are driven by the persistent narrowing of the gap towards its steady state. Lastly, the dynamics of the medium-run growth rate are solely influenced by the cyclical behaviour of the output gap (panel (f)).

8.2. A demand shock

Figure 7 shows the response of the main variables resulting from a shock to e_t^y with a magnitude of $\Delta\bar{y} = 0.33$. As the shock enter the demand equation, the output gap immediately rises by about 0.3 percentage points. This causes an instantaneous increase in both inflation and labour demand since the output gap affects inflation and labour demand contemporaneously. The rise in labour demand subsequently drives up wages. Since the initial wage increase surpasses that of prices, the real wage gap becomes positive. These patterns are distinctly noticeable in the first bar of each panel in the figure.

After this initial shock, the variables start a slow return to their steady-state values. Panel (a) provides a factor breakdown of the output gap. The early demand response is dominated by the positive shock but is soon surpassed by intrinsic dynamics of the demand itself. The persistent nature of the output gap continues to sustain its level considerably above the steady state for an extended period. Contributions from other factors are negligible.

Panel (b) depicts the employment response. In contrast to the price shock, the dynamics here are mainly determined by the evolution of the output gap. Higher demand for goods and services elevates labour demand, thought to a lesser extent than the increase in the output gap itself. The response also reveals a slight persistence in labour demand influencing the employment gap. The corrective action from the real wage gap is negligible.

Panel (c) reveals the breakdown of the impulse response for inflation. The positive output gap remains the prevailing factor guiding the response. As inflation expectations pick up, they offset the dampening arising from convergence of the output gap to its steady state. Additionally, early in the response, the positive real wage gap exerts upward pressure on inflation. This turns negative towards the end of the response period, as the gap itself turns negative.

Panel (d) display the breakdown of the wage response. Following the initial shock, the dynamics are dominated by tight labour markets, as indicated by the combined influence of current and past employment gaps. In the initial stages of the response, the corrective pressure stemming from the real wage gap tends to suppress wage growth. Towards the end of the horizon, as the wage gap turns negative, the correction stemming from the negative wage gap tends to sustain wage growth, while the tightness in the labour market effectively disappears. Finally, inflation expectations play a negligible role in wage dynamics following a demand shock.

Panel (e) presents findings related to the real wage gap. Like before, this breakdown relies on the real wage gap identity. After its initial surge, the factor decomposition shows that the initial dominance of wage growth diminishes after the first two quarters. The subsequent dynamics highlight a gradual reduction of the gap towards its steady state. Lastly, the cyclical behaviour of the output gap solely determines the dynamics of the medium-run growth rate (panel (f)).

9. Forecasting out of sample

Focusing on the medium run provides a clearer understanding of the underlying trend in the data. However, this approach comes with drawbacks. By overlooking short-run fluctuations, important high-frequency events or shocks might be missed. Moreover, forecasts based solely on the medium run can be hard to align with actual data. This might result in perceived inaccuracies in the forecast, even if the medium-run trend is captured relatively well.

9.1. Forecast decomposition

Figure 8 presents forecasts of key variables derived from the model calibrated with parameters set at the mode. The last in-sample observation is for 2023Q2. Besides the forecast trajectory, the figure offers a decomposition of the forecasted variables by contributing factors. This exercise does not integrate any expert opinions. Forecasts rely on estimated parameters, current state estimates, and implicitly assume the absence of subsequent shocks. Thus, due to the stationarity of the system, forecasted outcomes tend to converge towards the steady state, irrespective of potential exogenous shocks that could arise, whether they are favourable or unfavourable.

Panel (a) portrays the forecast decomposition for inflation from 2023Q3 to 2027Q2. Variables shown are relative to the steady state, so a steady state value of 0.5 must be added to inflation to obtain the point forecast estimate. The forecast for inflation is quarter-on-quarter. The point estimate for 2023Q3 is 1.2 percent, while that for 2023Q4 is 1.1 percent. Combining these with medium-run values for inflation at the start of 2023, and converting it into year-on-year average inflation results in the annual inflation forecast for 2023 of 5.3 percent. Mean predictions for 2024, 2025, and 2026 are 4.1, 3.2, and 2.6 percent respectively. Inflation expectations, followed by the persistence of the price shock and a positive output gap, are the primary drivers of this forecast. Although the corrective force of the real wage gap dampens inflation, its impact is small. Meanwhile, the projections for each quarter relative to the same quarter in the previous year are 5.0, 3.7, 2.9, and 2.5 percent for the years 2023 to 2026, respectively.

Panel (b) provides the forecast decomposition for wage growth between 2023Q3 and 2027Q2. Given that the depicted variables are relative to the steady state, a value of around 0.6 should be added to obtain the point forecast estimate. The wage growth forecast is also quarter-on-quarter. Point estimates for 2023Q3 and 2023Q4 are 1.3 percent and 1.2 percent. Combining these with medium-run wage growth values from the beginning of 2023, the year-on-year average forecast for wage growth in 2023 is 5.4 percent. For 2024, 2025, and 2026, forecasts are 4.5, 3.7, and 3.1 percent, respectively. The forecast dynamics mainly stem from the corrective force of the real wage gap, with labour market tightness also playing a key role in the initial few quarters. Inflation expectations rank third. Meanwhile, the projections for each quarter, when compared to the same quarter of the previous year, are 5.2, 4.2, 3.4, and 3.0 percent for the years 2023 through 2026, respectively.

Panel (c) depicts the forecast decomposition for the output gap from 2023Q3 to 2027Q2. The output gap at the beginning of the forecast period is approximately 2.5 percent. Persistent aggregate demand chiefly drives the forecast dynamics. Current and expected inflation essentially balance each other in shaping demand dynamics, with a modest contribution from exogenous demand shocks. Panel (d) presents the forecast decomposition for the employment gap, which starts at 2.3 percent at the beginning of the period, underlining labour market tightness. The tightness is mainly attributed to the positive output gap. In addition, the negative real wage gap exerts minor upward pressure on the employment gap. Panel (e) displays the forecast for the real wage gap. Starting at negative 0.5 percent at the beginning of the forecast horizon, it progressively returns to its steady-state value over the subsequent years.

Panel (f) illustrates the forecast for the quarter-on-quarter medium-run growth rate of output. At the start of the forecast horizon, a decline of around 33 basis points is projected relative to the steady-state growth rate of 0.33 percent. The trajectory is indicative of a substantial contraction and a subsequent gradual recovery. Finally, while the cyclical component of the growth rate shows signs of recovery, the medium-run growth rate is still constrained by the sub-par long-run growth rate of output.

9.2. An update

The projections presented above are based on data up to and including the second quarter of 2023, which was downloaded on 15/09/2023. The data released in December for 2023Q3 shows a significant decline in headline inflation, making it worthwhile to re-estimate the model. This re-estimation allows for a comparison between the previous estimates and the updated ones, as well as generating a new set of projections. Regarding the estimated parameters, these are not significantly different from the previous estimates. In terms of projections, the updated forecasts for year-on-year average inflation from 2023 through 2026 are now 4.9, 3.5, 2.8, and 2.4 percent, respectively. Likewise, the quarter-on-quarter projections, when compared to the same quarters of the previous year, are 4.5, 3.2, 2.6, and 2.3 percent. For wages, the revised projections for average year-on-year growth rate from 2023 to 2026 are 5.3, 4.1, 3.3, and 2.9 percent, respectively. The quarter-on-quarter wage growth projections are 4.9, 3.7, 3.1, and 2.8 percent.

9.3. Discussion

9.3.1. On projections

The ECB and Eurosystem staff continuously produce macroeconomic forecasts. Panel (a) of Figure 9 provides these projections for inflation together with the forecasts generated by this framework. ECB September 2023 projections reveal that inflation in the euro area, measured using the GDP deflator, is anticipated to average 5.7 percent in 2023. This rate is expected to decline to 3.1 percent in 2024, further receding to 2.5 percent by 2025. Panel (b) displays projections for wage growth. For 2023, 2024 and 2025 the growth rate of nominal wages is expected to be 5.3, 4.3 and 3.8. In contrast to these projections, the above forecast paints a somewhat grimmer picture for the medium-run inflation path.

As previously discussed, the projection for inflation from the model is primarily influenced by inflation expectations. Panel (c) displays the annualised model-generated measure of inflation expectations, alongside forecasts for the current year and predictions for the next two years sourced from the ECB survey of professional forecasters. Policy circles frequently use these survey-based forecasts to gauge the trajectory of expectations. It is important to note that while survey-based measures are likely to be forward-looking, model-generated series are backward-looking. The figure suggests that the expectations produced by the model are more persistent compared to those from the survey.

Panel (d) displays annualised expectations at a quarterly frequency for both model-generated inflation expectations and survey expectations. Given that model-generated expectations are based largely on the previous four lags of the underlying inflation, it is not surprising to see that these series are smooth and reflect the underlying trend. Notably, the smoothed series of survey expectations aligns closely with the model-generated expectations. Running a simple ARIMA(1,0,0) on each series yields a persistence coefficient of 0.99 for the model-generated expectations and 0.92 for the survey-based expectations. These estimates underscore the previously mentioned stickiness of expectations, particularly those that are generated by the model. Consequently, the sizeable and enduring shock that transpired suggests a gradual decrease in expectations, leading to prolonged high inflation. This further emphasises the urgency for an accelerated monetary policy response.

9.3.2. On shortcomings

In general, differences in forecast outcomes often arise from variations in the methodologies used. Regarding the shortcomings of the current approach, the framework does not directly account for the prices of global intermediaries. Instead, it attributes these to the residual variation of the Phillips curve. Improved forecast accuracy might come from modelling this residual variation by analysing exogenous factors directly. Adopting statistically robust values for these external processes, especially ones that resonate with expert assessments, could reinforce forecasting accuracy.

Another notable omission is the neglect of fiscal policy within the current empirical framework. It is either relegated to the residual variation of the output gap or is implicitly incorporated into the gap itself. Given the significant impact of fiscal policy on aggregate demand, its modelling could provide a more nuanced understanding of inflationary trends and their underlying causes. Thus, integrating fiscal policy could yield better forecasts. Additionally, due to significant number of parameters to be estimated, the external sector has been left out. The latter, however, can be tightly linked with medium-run inflationary developments (Galstyan, 2019).

In addition, the recent wave of interest rate hikes has not yet been fully absorbed by aggregate demand. This suggests that the full implications of the ECB policy actions may not be entirely captured in the present data, which could skew estimates. It is worth noting that the recent surge in inflation is unparalleled in the euro area history.

Moreover, even with the aforementioned model enhancements, there is an underlying assumption that there have been no significant structural shifts in parameters. To account for potential shifts, continuous model re-estimation is essential, possibly employing a rolling window to prioritise recent data. However, given the nature of macroeconomic data, this approach would result in a reduced data sample, necessitating stronger priors.

The insights derived from the dynamic responses and factor decomposition offer coherent results. Model-generated annual output gap series are somewhat similar to the output gap estimated by the IMF, as shown in panel (e) of Figure 9. The employment gap series resemble the demeaned unemployment rate, as shown in panel (f) of Figure 9.

Combined, these lend credence to the plausibility of the results. Nevertheless, it is essential to recognise that there is always room for potential pitfalls, whether arising from the choice of Bayesian priors or specific nuances in the specification of the model itself.[24]

10. Conclusions

Understanding the dynamics of economic systems requires a multifaceted approach, encompassing the key variables across various time frames. By leveraging the logic of the New Keynesian model and disregarding inherent cross-parameter constraints, this paper provides an empirical framework and analysis of the interrelations among inflation, wages, employment, and output, with a focus on the euro area.

After estimating the model using Bayesian techniques coupled with data-informed priors, the endogenous variables are decomposed into contributions from relevant factors, and dynamic analysis is conducted. The primary exogenous shocks that explain historical variance are price shocks and shocks to aggregate demand. The results highlight the significance of the wage gap in driving wage dynamics following a price shock, while the output gap appears to be more important in response to demand shocks. In the current inflationary environment, of particular interest are the real wage gap and inflation expectations.

Adjustments in the real wage gap offer a valuable perspective for understanding wage dynamics in the euro area. Statistically, the real wage gap functions as a corrective mechanism, ensuring alignment of wages and prices with the broader economic landscape. The forecasting exercise suggest the persistent significance of the real wage gap in the coming years. By 2023, given a declining real wage gap, there are inherent implications for necessary adjustments in both wages and prices. The corrective force of the gap will likely continue to influence nominal wages in the presence of tight labour markets.

Regarding inflation expectations, the estimates underscore the stickiness of expectations. Given this backdrop, the significant and persistent shock that has occurred suggests a gradual decline in expectations, potentially leading to an extended period of high inflation. This reinforces the urgency for an accelerated monetary policy response.

Further extensions of the framework are warranted in at least two dimensions. Firstly,

[24] For a discussion on the estimation of DSGE models, see Blanchard (2016).

recognising that fiscal policy plays pivotal role in shifting aggregate demand, its analysis would provide a clearer understanding of inflation trends and their determinants. Secondly, the current framework does not directly incorporate global intermediary prices into the system, relegating them to the residual variation of the Phillips curve. Accounting for these two elements could enhance the accuracy of inflation forecasts.

Appendix: Comparison to Bernanke and Blanchard (2023)

The 2023 Bernanke-Blanchard paper has drawn significant attention in policy-making circles. Given its prominence, a comparison of the approach in this paper with theirs is merited. Their model incorporates three primary equations. The first key equation is the wage equation and is given by:[25]

$$w_t - w_{t-1} = Ep_t - p_{t-1} - \alpha(Ep_{t-1} - p_{t-1}) + \beta(x_t - \alpha x_{t-1}) + z_t^{\varpi} \tag{9}$$

Using the notation of the current paper, this equation can be rewritten as:

$$\pi_t^w = E\pi_t^p - \alpha(E\pi_{t-1}^p - \pi_{t-1}^p) + \beta\Delta x_t + \beta(1-\alpha)x_{t-1} + z_t^{\varpi} \tag{10}$$

The second key equation is the price equation, which, in differences, is expressed as:

$$p_t - p_{t-1} = (w_t - w_{t-1}) + (z_t^p - z_{t-1}^p) \tag{11}$$

where z_t^p is captured by commodity prices, proxies for supply chains, and trends in productivity. The equation can be rewritten using the notation of the current paper as follows:

$$\pi_t^p = \pi_t^w + \Delta z_t^p \tag{12}$$

Finally, there are two types of inflation expectations. The short-run inflation expectations are given by:

$$Ep_t - p_{t-1} = \delta\pi_t^* + (1-\delta)(p_{t-1} - p_{t-2}) \tag{13}$$

while the long-run expectations are expressed through:

$$\pi_t^* = \gamma\pi_{t-1}^* + (1-\gamma)(p_{t-1} - p_{t-2}) \tag{14}$$

The system presented in subsections 4.1 to 4.4 differs from the framework of Bernanke

[25]The equation is derived by assuming that the level of wages is determined according to $w_t = Ep_t + \varpi_t^A + \beta x_t$, where ϖ represents the real aspirational wage, intended to capture a 'catch-up' of wages to its desired level, and x_t denotes the slack in the labour market. The real aspirational wage is, in turn, given by: $\varpi_t^A = \alpha\varpi_{t-1}^A + (1-\alpha)(w_{t-1} - p_{t-1}) + z_t^{\varpi}$, with z_t^{ϖ} accounting for additional factors that influence the real aspirational wage.

and Blanchard (2023) along several key dimensions. In terms of timeframe, the paper primarily concentrates on medium-run cyclical patterns. However, achieving this requires modeling both short-run and long-run fluctuations.

In the long run, nominal frictions are absent, and macroeconomic variables remain unaffected by shocks from the short and medium run. This is consistent with the classical dichotomy, which suggests that monetary policy does not influence real economic factors in this timeframe. In the context of the long run, it is assumed that, in a steady state, real wages and output per employee grow at the same rate. Additionally, an equilibrium relationship between output, employment, and real wages is permitted in the long run, which can deviate from linear trends. Essentially, these variables each follow a unit root process with a drift.

Central to this paper is the medium run, where nominal frictions come into play and the classical dichotomy breaks down. In the medium run, nominal shocks have an impact on both nominal and real variables. Since medium-run shocks exclude high-frequency disturbances, the medium-run trend offers a clearer representation of the dynamic trajectory of variables. Specifically, when discussing inflation, the concept of 'underlying inflation' emerges as a medium-run phenomenon, stripping away short-run volatility to reveal foundational, persistent price movements. Importantly, for monetary policy, the future interest rate path is shaped by the medium-run trajectory of inflation. Lastly, short-run fluctuations are modelled as white noise.

Similar to Bernanke and Blanchard (2023), exponential smoothing is employed to model expectations. In the current framework, it captures medium-run inflation expectations. Long-run expectations are anchored to a policy rate of 0.5 percent, measured at a quarterly frequency. Bernanke and Blanchard (2023) consider both long-run and short-run expectations. While they also revert to the exponential smoothing equation, they directly incorporate forward-looking expectations using measures of expectation taken from the FED. In contrast, inflation expectations in the current paper are modelled as a function of past data only. In a high-inflation environment, this approach might have its shortcomings.

Contrary to the Bernanke-Blanchard approach, nominal wages are decoupled from direct price determination in the price Phillips curve. Meanwhile, inflation expectations directly influence price setting, beyond their manifestation through the wage equation.

To further allow for price and wage corrections towards their long-run values, the wage gap is incorporated into both the wage and price equations. The wage gap represents the deviation of the real wage from its long-run trend. In contrast, the 'catch-up' effect in Bernanke and Blanchard (2023) is modelled as the four-quarter average of CPI inflation minus the one-year inflation expectation from four quarters earlier.

Given the general equilibrium nature of the empirical system in this paper, both the output and employment gaps are endogenous. This contrasts with the Bernanke-Blanchard approach, where domestic slack is treated as exogenous. This distinction is crucial because, in the medium run, output is highly susceptible to changes in inflationary pressures, either directly through demand as modelled in this paper, or indirectly via the monetary policy stance. As a result, the system presented in this paper offers a richer set of dynamics. Lastly, an explicit distinction is made between the output gap and the employment gap, linking them through a modified Okun's law (see Gali, 2015).

In terms of empirical implementation, the current system comprises four observable variables, each with 113 observations. It also includes 18 unobservable endogenous variables and 30 parameters that are estimated. Except for the steady-state inflation, which is fixed at 0.5, all other parameters are estimated. All parameters of the empirical framework are determined using Bayesian methods, and latent variables are extracted with the Kalman filter. In contrast, Bernanke and Blanchard (2023) directly control for all variables; therefore, there are no priors that could influence the estimates and dynamics of the system. Additionally, they allow for a much broader lag structure when estimating their equations.

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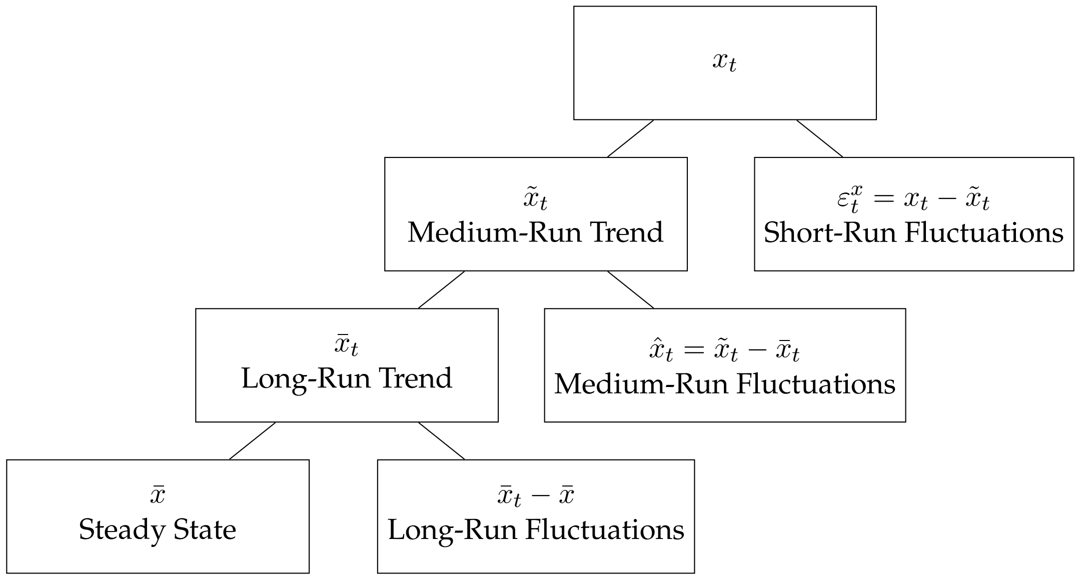
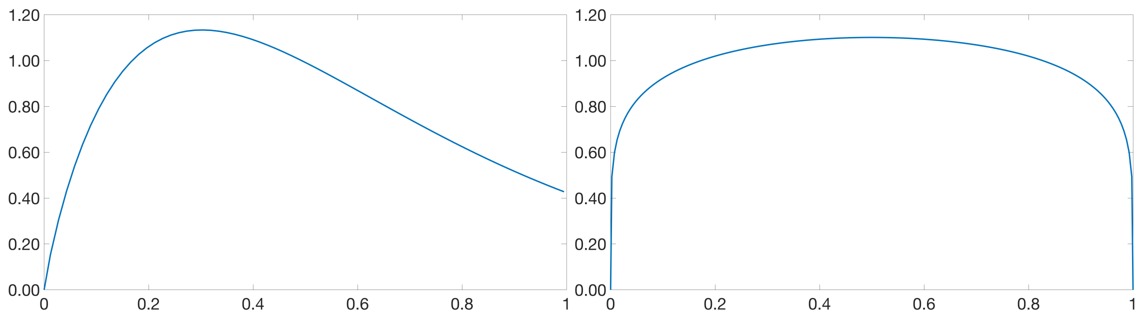
Figure 1: Time Horizon



Note: The figure provides a diagrammatic representation of the time horizon for a generic variable x_t. This horizon categorises economic timeframes into the steady state, long run, medium run, and short run.

Figure 2: Prior Distributions

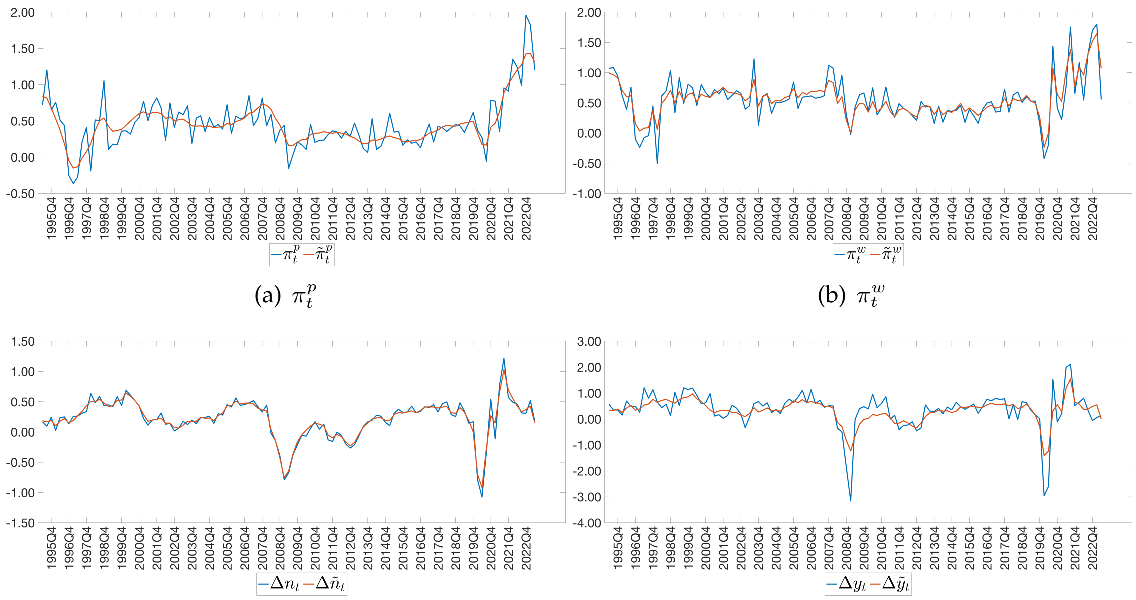


(a) Gamma

(b) Beta

Note: The figure illustrates the prior distributions. While the Gamma distribution is not constrained on the right, only the zero to one interval is plotted for clarity.

Figure 3: Signal and Noise

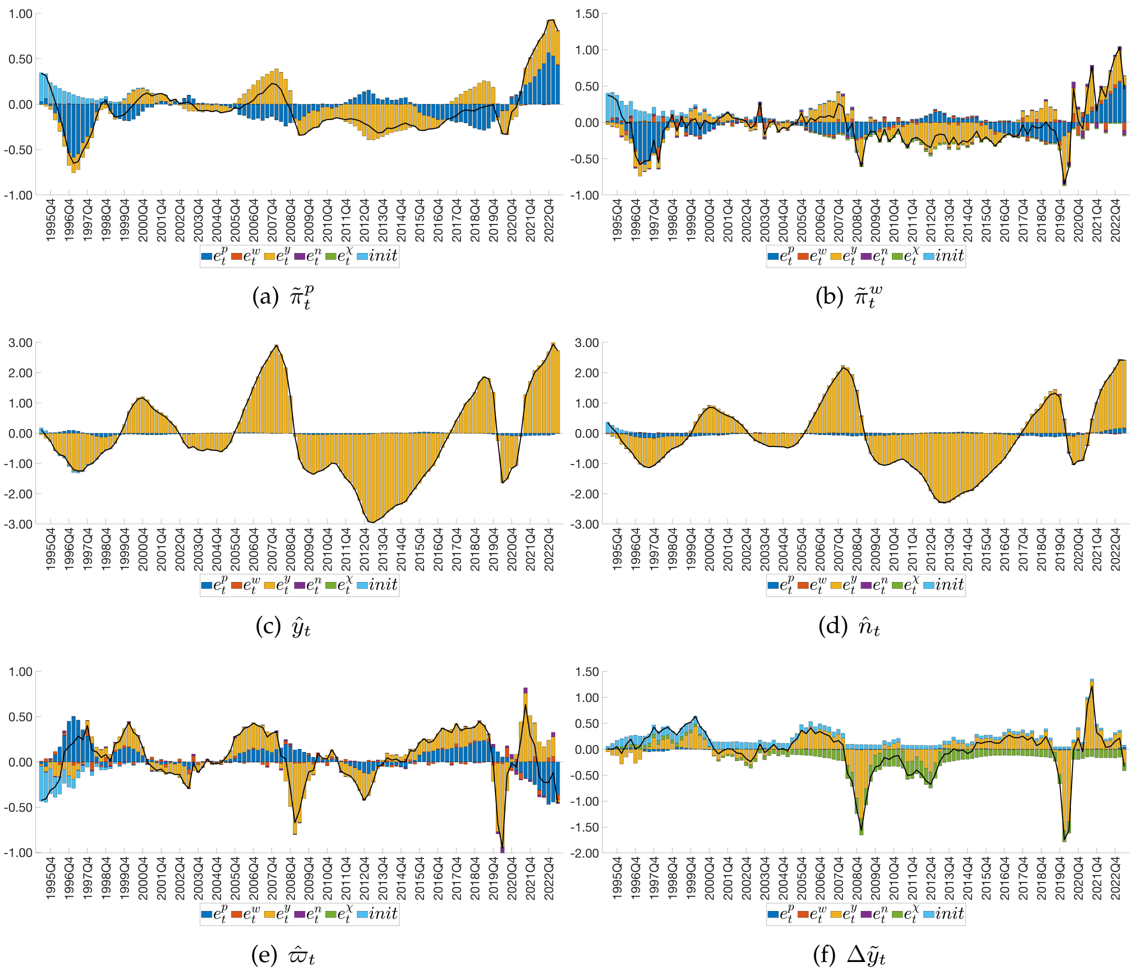


(a) π_t^p (b) π_t^w

(c) Δn_t (d) Δy_t

Note: The figure displays the actual series along with its corresponding medium-run trend. The last in-sample observation is for 2023Q2.

Figure 4: Shock Decomposition



(a) $\tilde{\pi}_t^p$

(b) $\tilde{\pi}_t^w$

(c) $\hat{y}_t$

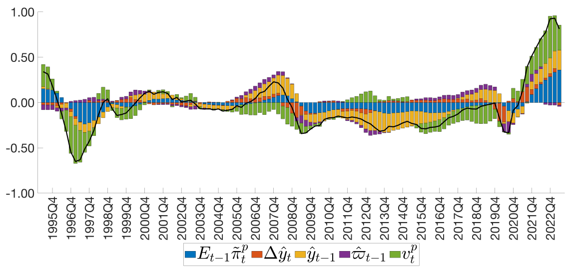
(d) $\hat{n}_t$

(e) $\hat{\varpi}_t$

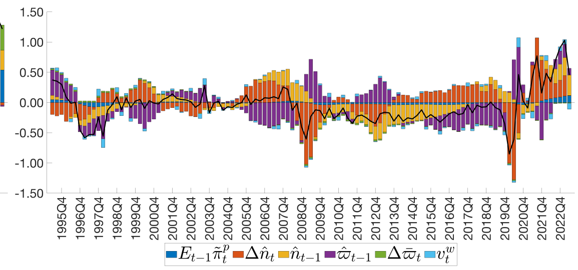
(f) $\Delta\tilde{y}_t$

Note: The figure illustrates the historical shock decomposition of key economic variables. The last in-sample observation is for 2023Q2. The variables are measured relative to the steady state. All gaps have a steady state value of zero. The quarterly steady-state value for inflation relative to the previous quarter is $\bar{\pi}^p = 0.5$. For wage growth, the quarterly steady-state value relative to the previous quarter is $\bar{\pi}^w = 0.61$. Meanwhile, the quarterly steady-state value for output growth compared to the previous quarter is $\Delta\bar{y} = 0.33$. The equations that describe the medium-run system are listed below.

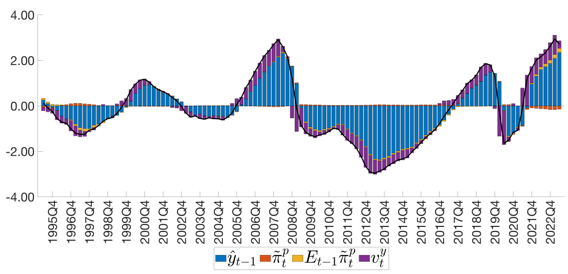
Figure 5: Factor Decomposition



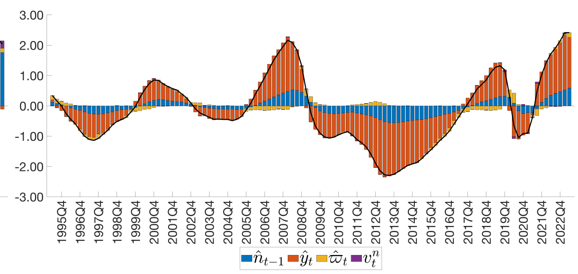
(a) $\tilde{\pi}^p_t$



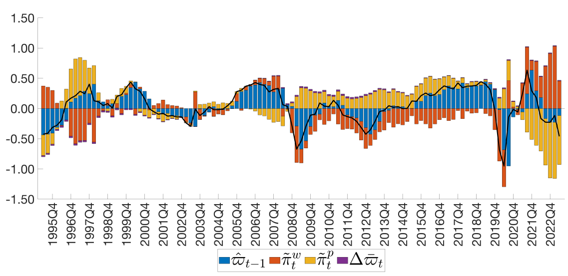
(b) $\tilde{\pi}^w_t$



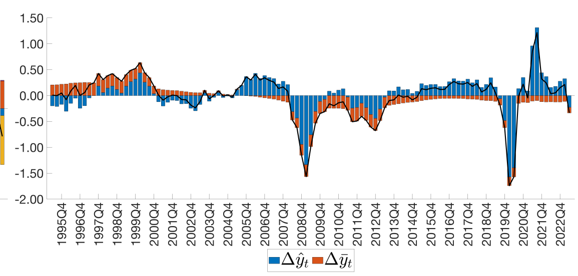
(c) $\hat{y}_t$



(d) $\hat{n}_t$



(e) $\hat{\varpi}_t$

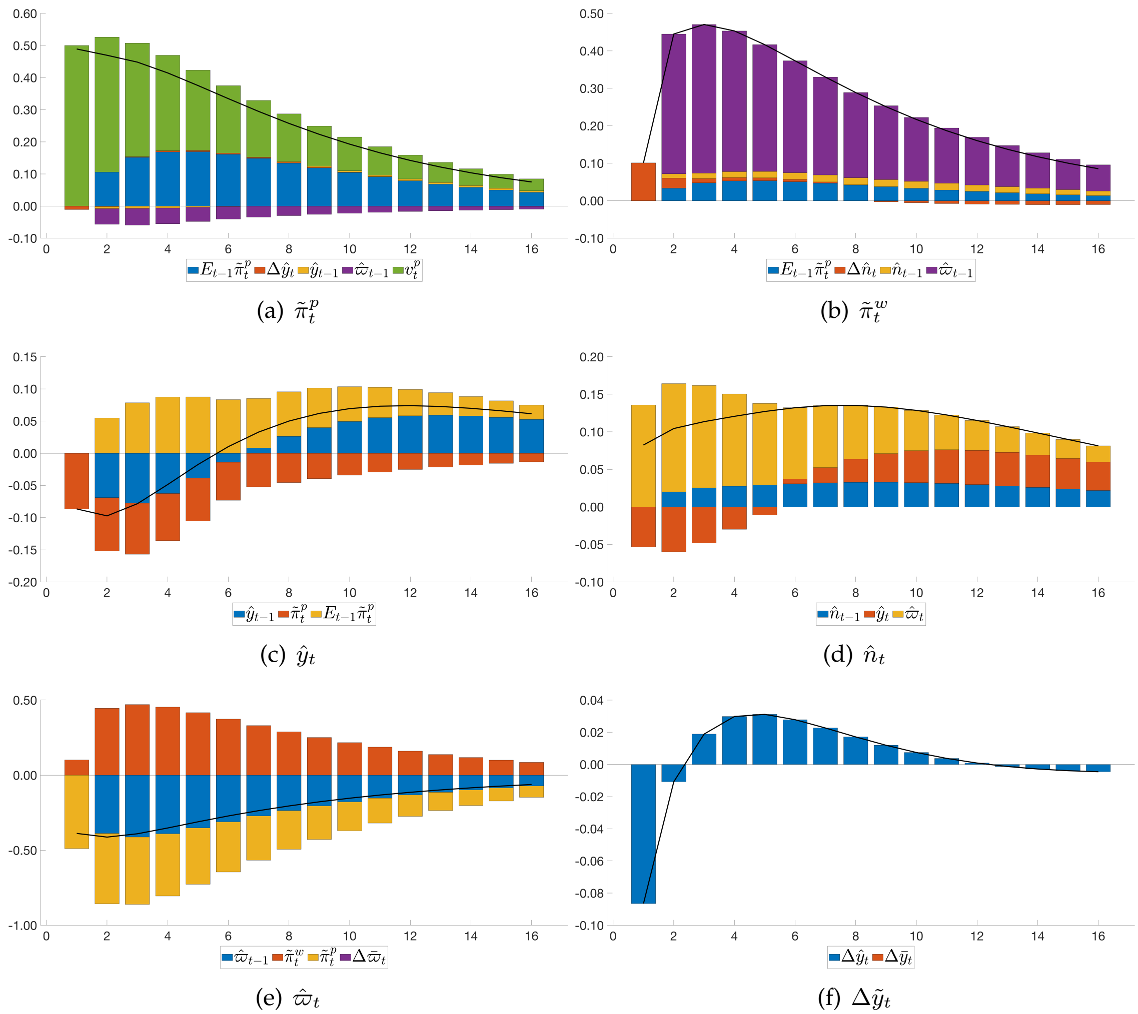


(f) $\Delta\tilde{y}_t$

Note: The figure illustrates the factor decomposition of key economic variables. The last in-sample observation is for 2023Q2. The variables are measured relative to the steady state. All gaps have a steady state value of zero. The quarterly steady-state value for inflation relative to the previous quarter is $\bar{\pi}^p = 0.5$. For wage growth, the quarterly steady-state value relative to the previous quarter is $\bar{\pi}^w = 0.61$. Meanwhile, the quarterly steady-state value for output growth compared to the previous quarter is $\Delta\bar{y} = 0.33$. The equations that describe the medium-run system are listed below.

$\tilde{\pi}^p_t - \bar{\pi}^p = \beta^p \left(E_{t-1}\tilde{\pi}^p_t - \bar{\pi}^p\right) + a_{p\Delta y}\Delta\hat{y}_t + a_{py}\hat{y}_{t-1} + a_{p\varpi}\hat{\varpi}_{t-1} + v^p_t$
$\tilde{\pi}^w_t - \tilde{\pi}^w_t = \beta^w \left(E_{t-1}\tilde{\pi}^p_t - \bar{\pi}^p\right) + a_{w\Delta n}\Delta\hat{n}_t + a_{wn}\hat{n}_{t-1} - a_{w\varpi}\hat{\varpi}_{t-1} + v^w_t$
$\hat{y}_t = \rho_y\hat{y}_{t-1} - a_{yp}\left(\tilde{\pi}^p_t - \bar{\pi}^p\right) + a_{ye}\left(E_{t-1}\tilde{\pi}^p_t - \bar{\pi}^p\right) + v^y_t$
$\hat{n}_t = \rho_n\hat{n}_{t-1} + a_{ny}\hat{y}_t - a_{n\varpi}\hat{\varpi}_t + v^n_t$

Figure 6: Response to a Shock e_t^p of Magnitude $\bar{\pi}^p$



(a) $\tilde{\pi}_t^p$ (b) $\tilde{\pi}_t^w$

(c) $\hat{y}_t$ (d) $\hat{n}_t$

(e) $\hat{\varpi}_t$ (f) $\Delta\tilde{y}_t$

Note: The figure illustrates the impulse response function of key economic variables to a shock e_t^p of magnitude $\bar{\pi}^p = 0.50$. The bars display the factor decomposition for each response variable. The dynamics are presented relative to the steady state. All gaps have a steady state value of zero. The quarterly steady-state value for inflation relative to the previous quarter is $\bar{\pi}^p = 0.5$. For wage growth, the quarterly steady-state value relative to the previous quarter is $\bar{\pi}^w = 0.61$. Meanwhile, the quarterly steady-state value for output growth compared to the previous quarter is $\Delta\bar{y} = 0.33$. The equations that describe the medium-run system are listed below.

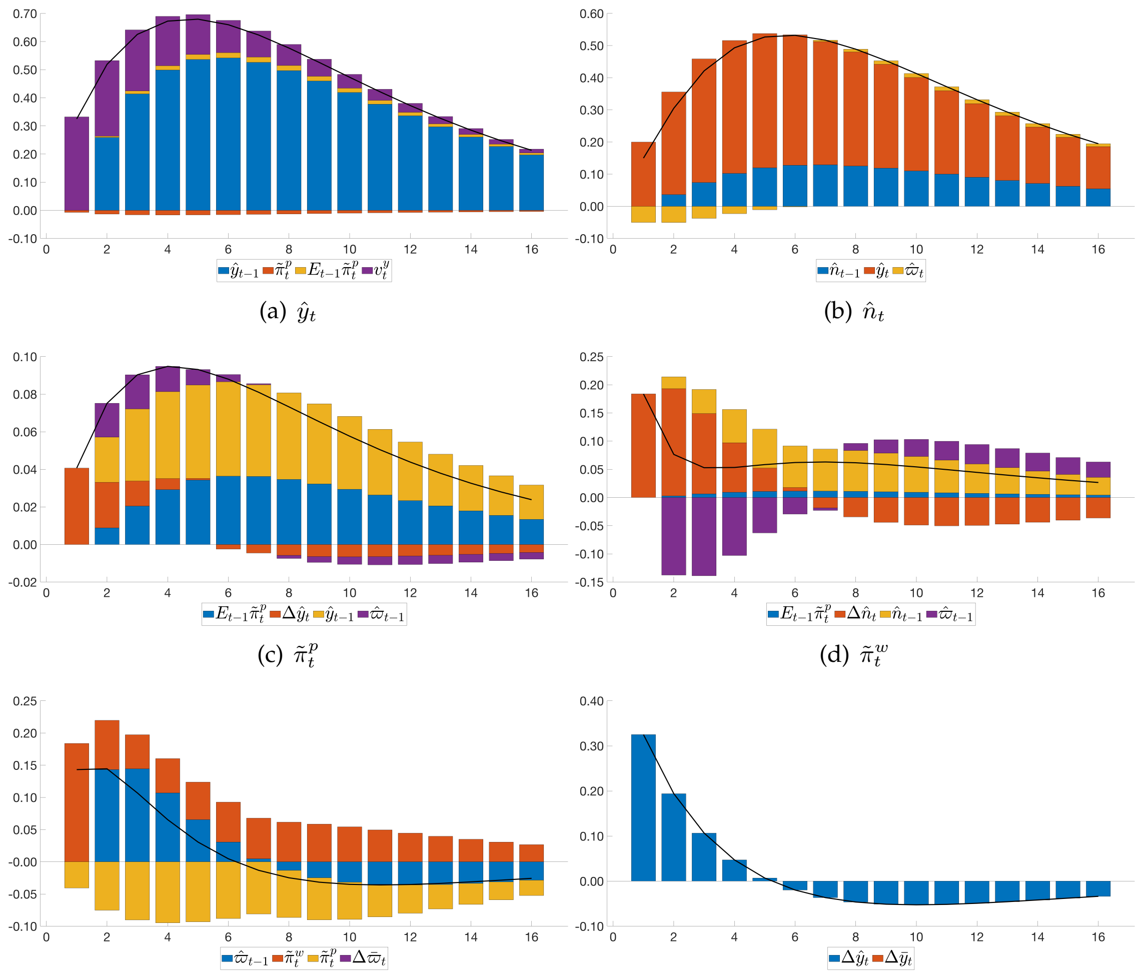
$\tilde{\pi}_t^p - \bar{\pi}^p = \beta^p \left(E_{t-1}\tilde{\pi}_t^p - \bar{\pi}^p\right) + a_{p\Delta y}\Delta\hat{y}_t + a_{py}\hat{y}_{t-1} + a_{p\varpi}\hat{\varpi}_{t-1} + v_t^p$

$\tilde{\pi}_t^w - \tilde{\pi}_t^w = \beta^w \left(E_{t-1}\tilde{\pi}_t^p - \bar{\pi}^p\right) + a_{w\Delta n}\Delta\hat{n}_t + a_{wn}\hat{n}_{t-1} - a_{w\varpi}\hat{\varpi}_{t-1} + v_t^w$

$\hat{y}_t = \rho_y\hat{y}_{t-1} - a_{yp}\left(\tilde{\pi}_t^p - \bar{\pi}^p\right) + a_{ye}\left(E_{t-1}\tilde{\pi}_t^p - \bar{\pi}^p\right) + v_t^y$

$\hat{n}_t = \rho_n\hat{n}_{t-1} + a_{ny}\hat{y}_t - a_{n\varpi}\hat{\varpi}_t + v_t^n$

Figure 7: Response to a Shock e_t^y of Magnitude $\Delta\bar{y}$



(a) $\hat{y}_t$ (b) $\hat{n}_t$

(c) $\tilde{\pi}_t^p$ (d) $\tilde{\pi}_t^w$

(e) $\hat{\varpi}_t$ (f) $\Delta\tilde{y}_t$

Note: The figure illustrates the impulse response function of key economic variables to a shock e_t^y of magnitude $\bar{y} = 0.33$. The bars display the factor decomposition for each response variable. The dynamics are presented relative to the steady state. All gaps have a steady state value of zero. The quarterly steady-state value for inflation relative to the previous quarter is $\bar{\pi}^p = 0.5$. For wage growth, the quarterly steady-state value relative to the previous quarter is $\bar{\pi}^w = 0.61$. Meanwhile, the quarterly steady-state value for output growth compared to the previous quarter is $\Delta\bar{y} = 0.33$. The equations that describe the medium-run system are listed below.

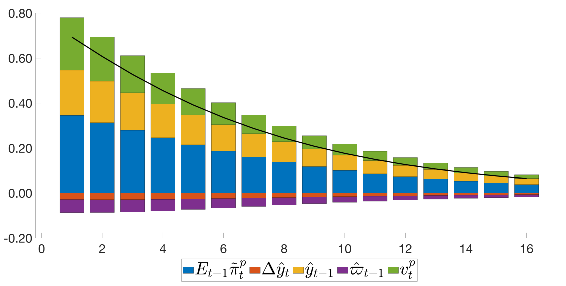
$\tilde{\pi}_t^p - \bar{\pi}^p = \beta^p \left(E_{t-1}\tilde{\pi}_t^p - \bar{\pi}^p\right) + a_{p\Delta y}\Delta\hat{y}_t + a_{py}\hat{y}_{t-1} + a_{p\varpi}\hat{\varpi}_{t-1} + v_t^p$

$\tilde{\pi}_t^w - \tilde{\pi}_t^w = \beta^w \left(E_{t-1}\tilde{\pi}_t^p - \bar{\pi}^p\right) + a_{w\Delta n}\Delta\hat{n}_t + a_{wn}\hat{n}_{t-1} - a_{w\varpi}\hat{\varpi}_{t-1} + v_t^w$

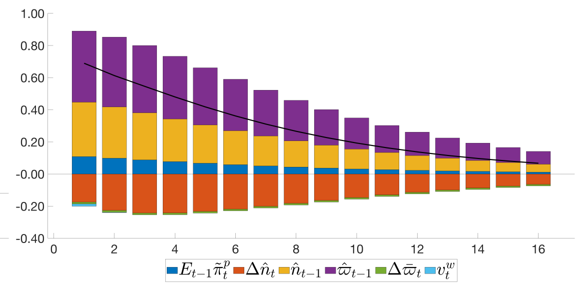
$\hat{y}_t = \rho_y\hat{y}_{t-1} - a_{yp}\left(\tilde{\pi}_t^p - \bar{\pi}^p\right) + a_{ye}\left(E_{t-1}\tilde{\pi}_t^p - \bar{\pi}^p\right) + v_t^y$

$\hat{n}_t = \rho_n\hat{n}_{t-1} + a_{ny}\hat{y}_t - a_{n\varpi}\hat{\varpi}_t + v_t^n$

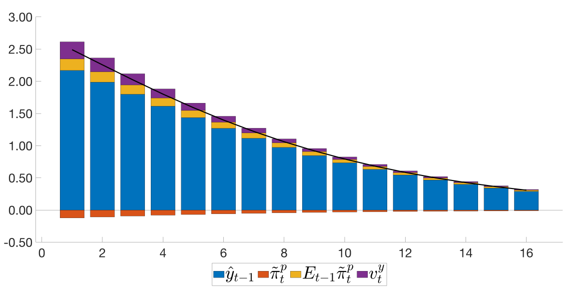
Figure 8: Out-of-Sample Forecasts



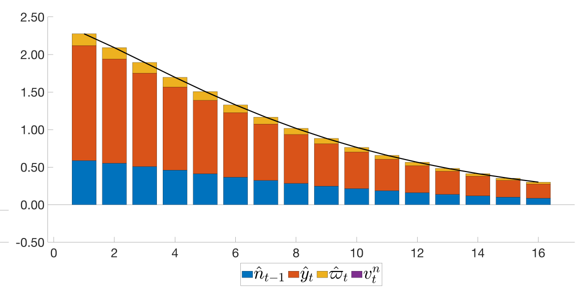
(a) $\tilde{\pi}^p_t$



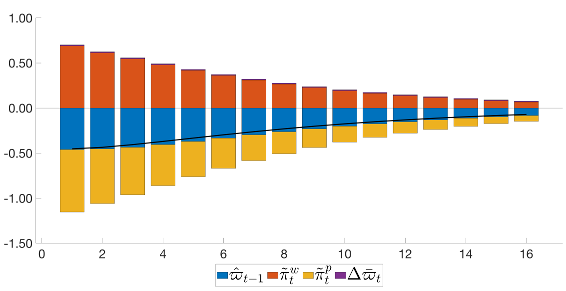
(b) $\tilde{\pi}^w_t$



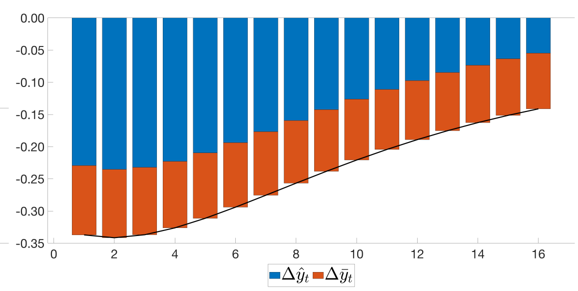
(c) $\hat{y}_t$



(d) $\hat{n}_t$



(e) $\hat{\varpi}_t$



(f) $\Delta\tilde{y}_t$

Note: The figure illustrates the out-of-sample forecast for key economic variables. The last in-sample observation is for 2023Q2. The bars display the factor decomposition for each forecast variable. The dynamics are presented relative to the steady state. All gaps have a steady state value of zero. The quarterly steady-state value for inflation relative to the previous quarter is $\bar{\pi}^p = 0.5$. For wage growth, the quarterly steady-state value relative to the previous quarter is $\bar{\pi}^w = 0.61$. Meanwhile, the quarterly steady-state value for output growth compared to the previous quarter is $\Delta\bar{y} = 0.33$. The equations that describe the medium-run system are listed below.

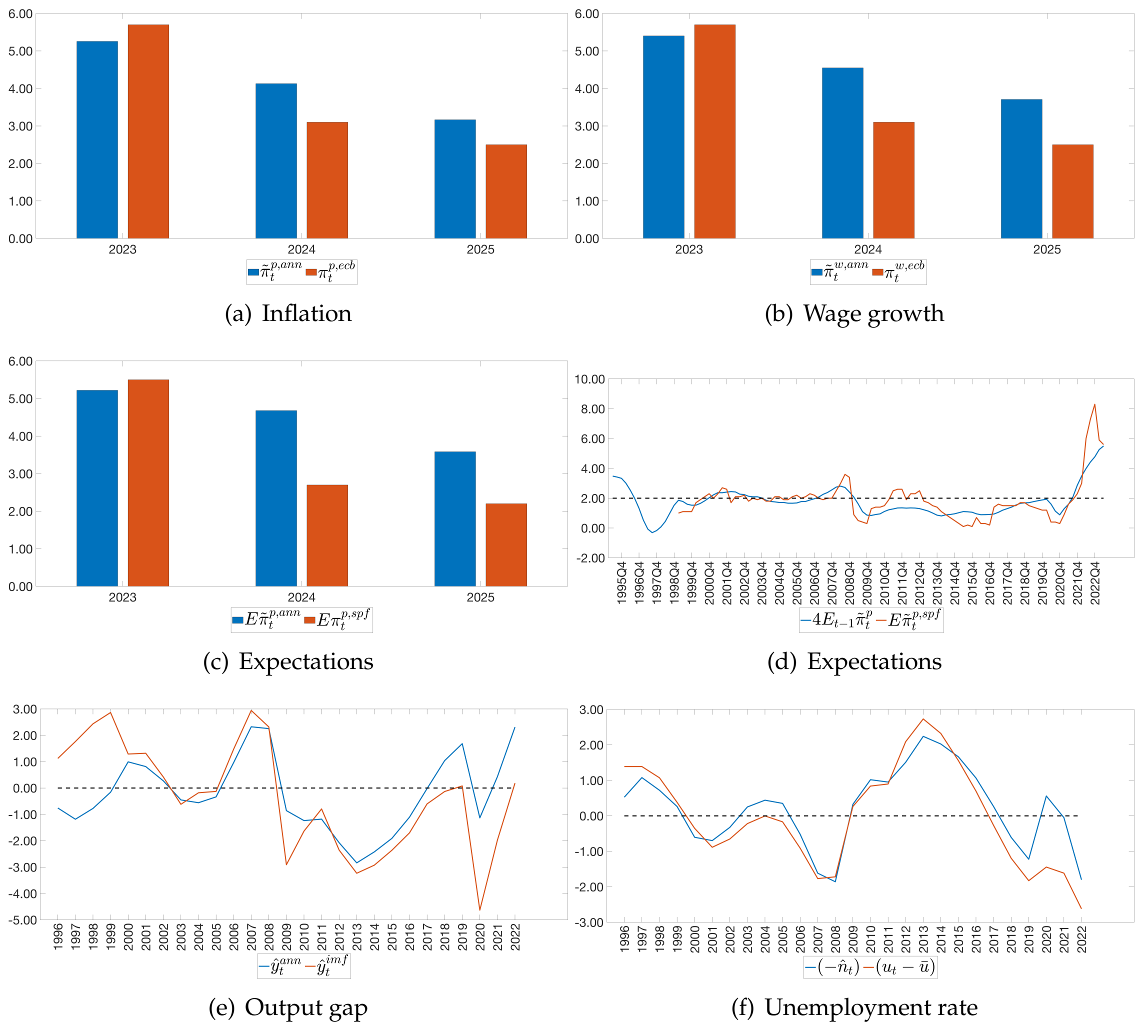
$\tilde{\pi}^p_t - \bar{\pi}^p = \beta^p \left(E_{t-1}\tilde{\pi}^p_t - \bar{\pi}^p\right) + a_{p\Delta y}\Delta\hat{y}_t + a_{py}\hat{y}_{t-1} + a_{p\varpi}\hat{\varpi}_{t-1} + v^p_t$

$\tilde{\pi}^w_t - \bar{\pi}^w_t = \beta^w \left(E_{t-1}\tilde{\pi}^p_t - \bar{\pi}^p\right) + a_{w\Delta n}\Delta\hat{n}_t + a_{wn}\hat{n}_{t-1} - a_{w\varpi}\hat{\varpi}_{t-1} + v^w_t$

$\hat{y}_t = \rho_y\hat{y}_{t-1} - a_{yp}\left(\tilde{\pi}^p_t - \bar{\pi}^p\right) + a_{ye}\left(E_{t-1}\tilde{\pi}^p_t - \bar{\pi}^p\right) + v^y_t$

$\hat{n}_t = \rho_n\hat{n}_{t-1} + a_{ny}\hat{y}_t - a_{n\varpi}\hat{\varpi}_t + v^n_t$

Figure 9: Comparison



(a) Inflation

(b) Wage growth

(c) Expectations

(d) Expectations

(e) Output gap

(f) Unemployment rate

Note: In Panel (a), ECB projections for inflation are presented alongside forecasts produced by the current framework. Panel (b) provides ECB projections for wage growth, again paired with forecasts from the current framework. Panel (c) offers annualised projections of model-generated inflation expectations, complemented by the annual inflation forecast from the ECB survey of professional forecasters. Panel (d) illustrates annualised inflation expectations at a quarterly frequency, comparing model-generated inflation expectations with those derived from the ECB survey of professional forecasters. Panel (e) displays the annual output gap series generated by the model, alongside the annual output gap series from IMF WEO dataset. Panel (f) shows the negative of the averaged quarterly model-generated employment gap over four quarters for a given year and the demeaned annual unemployment rate, sourced from WDI dataset.

Table 1: Summary Statistics

	(1) π_t^p	(2) π_t^w	(3) Δn_t	(4) Δy_t
Sample Mean	0.456	0.548	0.214	0.360
Sample St.Dev.	(0.359)	(0.378)	(0.322)	(0.732)
OLS st.err.	(0.034)***	(0.036)***	(0.030)***	(0.069)***
Observations	113	113	113	113

Note: The first two rows of the table provide in-sample means and standard deviations for the four observable macroeconomic variables. The last row presents the OLS standard error from a regression of the variable in question on a constant. Robust standard errors are shown in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Table 2: Priors for Shocks

	(1) π_t^p	(2) π_t^w	(3) Δn_t	(4) Δy_t
$SD(\varepsilon_t^x)$	0.205	0.279	0.201	0.564
	(0.017)***	(0.032)***	(0.029)***	(0.078)***
$SD(e_t^x)$	0.080	0.101	0.073	0.210
	(0.007)***	(0.008)***	(0.010)***	(0.026)***
$SD(\varepsilon_t^x)/SD(e_t^x)$	2.551	2.776	2.739	2.680
	(0.214)***	(0.312)***	(0.350)***	(0.286)***
Observations	109	109	109	109

Note: The table provides the results from a state-space estimation, as explained in sub-section 4.1. These are then used as priors in the Bayesian estimation. Robust standard errors are shown in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Table 3: Posterior Estimation of Parameters

		Prior		Posterior				
	Distr.	Mean	St.Dev	Mode	St.Dev	Mean	5 percent	95 percent
θ	Beta	0.500	0.273	0.528	0.306	0.456	0.001	0.808
β^p	Beta	0.500	0.273	0.410	0.338	0.438	0.038	0.785
$a_{p\Delta y}$	Gamma	0.644	0.469	0.125	0.071	0.138	0.026	0.240
a_{py}	Gamma	0.644	0.469	0.074	0.056	0.095	0.012	0.173
$a_{p\varpi}$	Beta	0.500	0.273	0.126	0.139	0.192	0.000	0.362
ρ_{v^p}	Beta	0.500	0.273	0.841	0.117	0.809	0.635	0.988
β^w	Beta	0.500	0.273	0.129	0.271	0.373	0.000	0.739
$a_{w\Delta n}$	Gamma	0.644	0.469	1.226	0.232	1.252	0.851	1.646
a_{wn}	Gamma	0.644	0.469	0.140	0.103	0.161	0.016	0.294
$a_{w\varpi}$	Beta	0.500	0.273	0.962	0.087	0.860	0.706	1.000
ρ_{v^w}	Beta	0.500	0.273	0.148	0.345	0.545	0.119	0.990
ρ_n	Beta	0.500	0.273	0.243	0.186	0.254	0.012	0.455
a_{ny}	Gamma	0.644	0.469	0.615	0.141	0.707	0.453	0.947
$a_{n\varpi}$	Gamma	0.644	0.469	0.350	0.226	0.512	0.103	0.884
ρ_{v^n}	Beta	0.500	0.273	0.535	0.599	0.528	0.137	0.978
ρ_y	Beta	0.500	0.273	0.797	0.125	0.774	0.596	0.970
a_{yp}	Gamma	0.644	0.469	0.177	0.186	0.440	0.020	0.858
a_{ye}	Gamma	0.644	0.469	0.212	0.219	0.391	0.015	0.761
ρ_{v^y}	Beta	0.500	0.273	0.809	0.113	0.787	0.636	0.946

Note: The posterior distribution is obtained using the Metropolis-Hastings algorithm. The estimations are performed in DYNARE with a single chain consisting of 10 million draws, an acceptance rate of 31 percent, and a 50 percent burn-in.

Table 4: Posterior Estimation of Shock Variance

	Prior			Posterior				
	Distr.	Mean	St.Dev	Mode	St.Dev	Mean	5 percent	95 percent
λ	Normal	2.700	0.300	1.875	0.284	1.895	1.434	2.349
ε_t^p	Normal	0.205	0.017	0.201	0.011	0.203	0.184	0.222
ε_t^w	Normal	0.279	0.032	0.224	0.020	0.237	0.204	0.271
ε_t^n	Normal	0.201	0.029	0.110	0.016	0.114	0.089	0.141
ε_t^y	Normal	0.564	0.078	0.523	0.037	0.533	0.472	0.594

Note: The posterior distribution is obtained using the Metropolis-Hastings algorithm. The estimations are performed in DYNARE with a single chain consisting of 10 million draws, an acceptance rate of 31 percent, and a 50 percent burn-in.

Table 5: Variance Decomposition

	e_t^p	e_t^w	e_t^y	e_t^n	e_t^χ
$\tilde{\pi}_t^p$	56.8	0.1	43.0	0.0	0.0
$\tilde{\pi}_t^w$	47.5	7.3	41.1	3.4	0.7
$E_{t-1}\tilde{\pi}_t^p$	55.5	0.1	44.4	0.0	0.0
$\hat{y}_t$	0.1	0.0	99.9	0.0	0.0
$\hat{n}_t$	0.6	0.1	99.1	0.3	0.0
$\hat{\varpi}_t$	43.3	7.2	46.8	2.7	0.0

Note: The table presents the variance decomposition of key macroeconomic variables, with parameters calibrated to the estimated mode.

T: +353 (0)1 224 5800
E: publications@centralbank.ie
www.centralbank.ie

Banc Ceannais na hÉireann
Central Bank of Ireland
Eurosystem