

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

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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 2023:Q4 emphasize the enduring significance of the real wage gap, projecting its ongoing impact on nominal wages in tight labor markets. As for inflation expectations, the estimates emphasize 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.

JEL Codes: E00, E12, E30, E31, E32, E37.

1. Introduction

The resurgence of inflation in 2022, following a prolonged period of subdued price dynamics, represents one of the most critical macro-economic developments of the post-pandemic era. The euro area, in particular, witnessed an annualized price growth of 10.6 percent in October 2022, a significant jump from near-zero levels recorded just two years prior. These pressures erode purchasing power, heighten

*I thank Philip Lane, Reamon Lydon, Enrico Sette, and two anonymous referees 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. Author email: vahagn.galstyan@centralbank.ie.

economic uncertainty, and threaten overall macroeconomic stability. Given the considerable costs of high inflation, understanding its underlying dynamics through empirical analyses becomes imperative. This paper contributes to the ongoing debate on inflation dynamics by analyzing the drivers of inflation and wage growth in the euro area.

Drawing on New Keynesian theory, this paper develops an empirical framework that models demand and supply in both the goods and labor markets. The primary focus is on medium-run cyclical dynamics; however, capturing these requires accounting for both short-term fluctuations and long-term trends. For simplicity, the empirical framework adopts the specification set out in Galí (2015), which comprises four equations. 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 describes nominal wage growth as a function of inflation expectations, labor market slack, and the real wage gap. The third equation describes aggregate demand as a function of both current and expected inflation. The fourth is a version of Okun's law. This structure combines theoretical rigor with empirical flexibility, making it well-suited for analyzing macroeconomic interactions and consistent with established modeling approaches.¹

This approach shares conceptual similarities with the dynamic empirical model of U.S. inflation developed by Bernanke and Blanchard (2023), which links prices, wages, and inflation expectations using a partial equilibrium framework. They use the vacancy-to-unemployment ratio as a measure of economic slack to assess the effects of both product market and labor market shocks during the pandemic, attributing the 2021 inflation spike primarily to commodity-driven price shocks.² However, the approach taken in this paper differs from their methodology in several important respects. In particular, instead of survey-based expectations, inflation expectations are modeled using only past data. Galstyan (2021)

¹The model builds on the New Keynesian Phillips curve (Woodford 2003), with related frameworks by Calvo (1983), Mankiw and Reis (2002), Gertler and Leahy (2008), and Gabaix (2020). See Eser et al. (2020) on the role of the Phillips curve in monetary policy at the ECB.

²Refer to the appendix for details on Bernanke and Blanchard (2023).

provides empirical support for this backward-looking specification, showing that lagged headline inflation explains a large share of variation in short-term expectations. While this modeling approach may reduce forecasting accuracy during periods of high inflation, it remains a pragmatic choice given the relatively stable inflation environment over much of the sample period.

Furthermore, this paper treats domestic economic slack (both the output and employment gaps) as endogenous, allowing feedback effects between macroeconomic conditions and inflation. By explicitly distinguishing the output gap from the employment gap (linked via a modified version of Okun's law), the model clarifies distinct channels: labor market tightness directly influences wage dynamics, whereas aggregate demand affects labor demand. This distinction enables a more detailed analysis of how shocks originating in goods and labor markets influence inflation dynamics. Additionally, to preserve tractability, the model adopts a parsimonious lag structure that prioritizes richer interactions over extended historical dependencies. Finally, although it uses equation structures similar to those in the work of Bernanke and Blanchard, it further filters out volatility from latent medium-run and long-run variables. This temporal separation helps isolate the "underlying" inflation trend and sheds light on the persistent drivers of inflation.

These modeling choices also position the paper well within several strands in the inflation literature. For instance, Lorenzoni and Werning (2023) develop a model in which inflationary spiral can emerge from disagreements between workers and firms over real wage levels, with the disagreements tied to the magnitude of the output gap. Their analysis shows that even if real wages move in response to shocks, this does not necessarily confirm the presence of a wage-price spiral. The current paper contributes to this literature by explicitly modeling the real wage gap as a key adjustment mechanism. This gap serves as an error-correction term, allowing the model to capture delayed wage responses following relative price shocks—an especially relevant feature in the euro-area context.

Looking at the role of inflation expectations in shaping inflation, Werning (2022) argues that the influence of expectations depends on their time horizon: near-term expectations have a much stronger effect on inflation than longer-term ones. He also shows that the pass-through varies across pricing models and is not necessarily close

to one. These insights are reflected in the empirical findings of this paper, which suggest that medium-run expectations play an important but moderated role, with estimated pass-through coefficients well below one.

Another area of research examines nonlinearities in the relationship between labor market tightness and wage or price dynamics. Benigno and Eggertsson (2023) model nonlinear effects of labor market conditions on inflation, and attribute much of the 2020s U.S. inflation to labor market tightness. Hahn (2020) and Harding, Lindé, and Trabandt (2023) similarly highlight asymmetric Phillips curve responses, especially in periods of low slack or high inflation. De Santis and Tornese (2023) show that energy shocks can transmit more forcefully to consumer prices under high inflation regimes, suggesting further state dependence. In contrast, Bernanke and Blanchard (2023) find that a linear model provides a good approximation of U.S. inflation dynamics. Similarly, recent evidence by Lo Bello and Viviano (2024) finds little support for pronounced nonlinearities in the Phillips curve for the euro area, providing justification for a linear empirical specification adopted in this paper.

Finally, a set of studies focuses specifically on the structural determinants of inflation in 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. Based on Shapiro (2022), Gonçalves and Koester (2022) decompose inflation into demand-driven and supply-driven components, showing that inflation during the early stages of the pandemic recovery was dominated by supply shocks, including energy prices and labor shortages, but gradually shifted toward demand factors, especially in services. Bobeica, Ciccarelli, and Vansteenkiste (2019) examine the price-wage relationship in the euro area, finding that the strength of pass-through depends on the nature of the shock and the inflation regime. Hansen, Toscani, and Zhou (2023) highlight the role of import prices and profit margins in explaining recent euro-area inflation.

Summarizing the findings, the shock decomposition reveals that price shocks and shocks to aggregate demand are the principal

exogenous factors explaining historical variance. This is further enriched by the factor decomposition. Between 2019:Q1 and mid-2021, the euro area experienced shifts in inflation dynamics, with the COVID-19 pandemic creating significant disruptions in 2020. While the labor market was robust pre-pandemic, supporting wage growth, the onset of COVID-19 suppressed wages and output. By 2023:Q3, a synergy of price shocks, rising inflation expectations, a rebounding output gap, and labor market recovery pushed inflation and wage growth beyond their pre-pandemic levels.

The impulse response analysis shows that a price shock causes an immediate increase in inflation, which in turn creates a negative real wage gap and stimulates 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 labor 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 emphasize 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 2023:Q3 onward, the output gap at the beginning of the forecast is approximately 2.2 percent, signaling overheating. The employment gap starts at around 2.0 percent, indicating a tightness in the labor 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 0.3 percent at the beginning of the forecast horizon.

In relation to inflation and wages, the 2023 year-on-year average inflation rate (GDP deflator) is expected to be 5.2 percent. It is influenced primarily by inflation expectations, followed by the persistence of the price shock and a positive output gap. The estimates emphasize 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 3.8, 2.9, and 2.5 percent, respectively. Meanwhile, wage growth for 2023 is projected to be 5.3 percent. For 2024, 2025, and 2026,

forecasts are 4.3, 3.5, and 3.0 percent, respectively. The dynamics of adjustment are driven largely by the corrective effects of the real wage gap and labor market tightness, with inflationary expectations also playing a role.

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

2. 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.³

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.⁴

Wages are measured using per-employee compensation, calculated from the ratio of employee compensation to the number of employees.⁵ Data for total employment are used to calculate the growth rate of employment.⁶ Chain-linked GDP in constant 2015 prices is used to measure the growth rate of output.⁷

³The data were downloaded on 03/07/2024.

⁴Series code: PD15_EUR,SCA,B1GQ,EA19.

⁵Series codes: CP_MEUR,SCA,D1,EA19 and THS.PER,SCA,SAL_DC,EA19.

⁶Series code: THS.PER,SCA,EMP_DC,EA19.

⁷Series code: CLV15_MEUR,SCA,B1GQ,EA19.

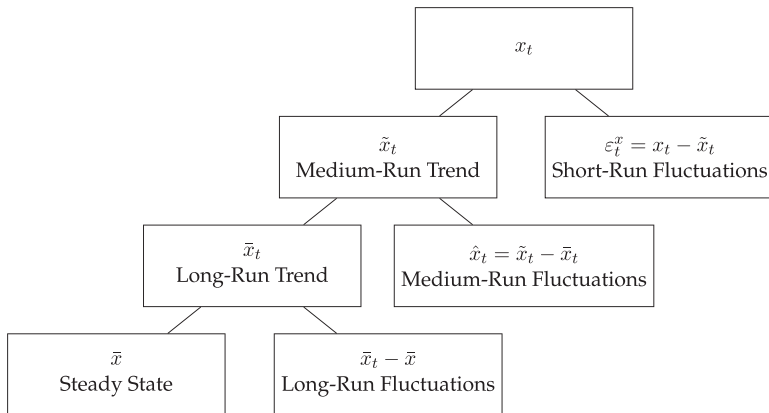
Table 1. Summary Statistics

	(1) π_t^p	(2) π_t^w	(3) Δn_t	(4) Δy_t
Sample Mean	0.461	0.561	0.214	0.362
Sample St. Dev.	(0.364)	(0.388)	(0.319)	(0.730)
OLS St. Err.	(0.034)***	(0.036)***	(0.030)***	(0.068)***
Observations	114	114	114	114
Note: The first two rows of the table provide in-sample means and standard deviations for the four observable macroeconomic variables. The third 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 percent, 5 percent, and 10 percent levels, respectively.				

The data set, in terms of levels of the variables, spans from the first quarter of 1995 to the third quarter of 2023. This time frame encompasses the COVID-19 era. In order to maintain this timeline while minimizing 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 2020:Q1 and 2020:Q3.⁸ 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 1995:Q2 to 2023:Q3.

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 means of these variables stand at 0.46, 0.56, 0.21, and 0.36, respectively, paired with corresponding sample standard deviations of 0.36, 0.39, 0.32, and 0.73. The high standard deviations in growth rates of output and

⁸Using a smoothing parameter equal to one results in the least possible smoothing. In this scenario, the fluctuations observed during the COVID period are reduced to a magnitude somewhat similar to those of the Global Financial Crisis. Thus, while the series is smoothed, it is not smoothed sufficiently to entirely eliminate the effects of the COVID period.

Figure 1. Time Horizon

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

employment are predominantly attributable to the substantial contractions during the Global Financial Crisis and the euro-area debt crisis. Toward the end of the sample period, all variables display pronounced volatility, largely due to the impact of the COVID-19 pandemic.

3. An Empirical Framework

3.1 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 categorizes economic time frames 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 European Central Bank (ECB) objective, its value in steady state is set at 0.5 percent (2 percent annualized). 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: $\Delta\bar{y} - \Delta\bar{n} = \Delta\bar{\omega}$.

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 time frame. 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 $\bar{x}_t \in (\bar{y}_t, \bar{\omega}_t, \bar{n}_t)$ 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: $\bar{\pi}_t^w = \Delta\bar{\omega}_t + \bar{\pi}^p$.

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 modeling, the medium-run trend of variable x_t is denoted by $\tilde{x}_t$. In this time frame, variables fluctuate around their long-run trend. For output, employment, and real wages, these fluctuations are denoted by a hat, and are referred 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 $\hat{\omega}_t - \hat{\omega}_{t-1} = \tilde{\pi}_t^w - \tilde{\pi}_t^p - \Delta \bar{\omega}_t$. 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 affecting the medium-run trend of the variables. Given the limited relevance of this time frame to the current paper, short-run fluctuations are modeled 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

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

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

3.2 Expectations

It is assumed that expectations are backward-looking ($E_{t-1} \tilde{\pi}_t^p$), and these are modeled with exponential smoothing.⁹ In particular, for a generic random variable x_t , the corresponding smoothed variable $\tilde{x}_t$ is defined as the weighted average of $\tilde{x}_{t-1}$ and x_{t-1} , with $\tilde{x}_t = (1 - \theta) \tilde{x}_{t-1} + \theta x_{t-1}$, where $\theta \in (0, 1)$.

Backward substitution shows that the exponentially smoothed variable is a weighted average of past realizations of the random variable x_t , with $\tilde{x}_t = \theta \sum_{j=1}^{\infty} (1 - \theta)^{j-1} x_{t-j}$. 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:

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

⁹For a link between exponential smoothing and state-space representation, see Hyndman et al. (2008).

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

3.3 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:

$$\begin{aligned}\tilde{\pi}_t^p - \bar{\pi}^p &= \beta^p (E_{t-1} \tilde{\pi}_t^p - \bar{\pi}^p) + a_{p\Delta y} \Delta \hat{y}_t \\ &+ a_{py} \hat{y}_{t-1} + a_{p\varpi} \hat{\varpi}_{t-1} + v_t^p.\end{aligned}\quad (3)$$

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.¹⁰ 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 assumed to follow a first-order autoregressive process.

Consistent with the rationale of the New Keynesian Phillips curve, higher demand results in the average markup falling short of its desired level, prompting firms to adjust prices upward. Similarly, a larger real wage gap leads to a below-desired average markup, 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 modeled as follows:

$$\hat{y}_t = \rho_y \hat{y}_{t-1} - a_{yp} (\tilde{\pi}_t^p - \bar{\pi}^p) + a_{ye} (E_{t-1} \tilde{\pi}_t^p - \bar{\pi}^p) + v_t^y. \quad (4)$$

¹⁰ As a theoretical reference, in the canonical New Keynesian model outlined by Galí (2015) in Chapter 7, the inflation Phillips curve adopts the following form: $\pi_t^p = \beta E_t \pi_{t+1}^p + \lambda_{py} \hat{y}_t + \lambda_{p\varpi} \hat{\varpi}_t$.

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 modeled 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:¹¹

$$i_t^p = r_t^n + \bar{\pi}^p + \frac{a_{yp}}{a_{ye}} (\tilde{\pi}_t^p - \bar{\pi}^p) + e_t^i.$$

With the assumed policy rule, the natural rate does not affect the output gap, conditional on the interest rate rule. A key advantage of this approach is that it avoids the need to model the nominal interest rate explicitly, which is empirically challenging given its persistent downward trend in the euro area over the sample period. This trend renders the nominal rate similar to a non-stationary series, complicating estimation. However, a potential drawback is that the model may understate the role of natural rate movements in the business cycle. Rules of other forms that do not neutralize the natural rate require the explicit modeling of the nominal interest rate.¹² In the present specification, residual variation in aggregate demand reflects both exogenous monetary policy shifts and other demand disturbances, which cannot be separately identified. Finally, the composite error v_t^y follows a first-order autoregressive process.

3.4 Labor 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

¹¹As a theoretical reference, in the canonical New Keynesian model described by Galí (2015) in Chapter 7, the corresponding equation takes the form $\hat{y}_t = E_t \hat{y}_{t+1} - \lambda_{yr} (i_t - E_t \pi_{t+1}^p - \tilde{r}_t)$.

¹²Regarding 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.

such as trends that are present in the data.¹³ Thus the wage Phillips curve is specified as follows:

$$\begin{aligned}\tilde{\pi}_t^w - \bar{\pi}_t^w &= \beta^w (E_{t-1} \tilde{\pi}_t^p - \bar{\pi}^p) + a_{w\Delta n} \Delta \hat{n}_t + a_{wn} \hat{n}_{t-1} \\ &\quad - a_{w\varpi} \hat{\varpi}_{t-1} + v_t^w,\end{aligned}\tag{5}$$

where $\bar{\pi}_t^w = \Delta \bar{\varpi}_t + \bar{\pi}^p$ and $\hat{n}_t$ measures the employment gap.¹⁴ 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.¹⁵ 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 Galí (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 labor supply curve. The relation states that a decline in labor demand, for a given level of labor supply, reduces employment. The resulting excess supply of labor causes wages to fall. Similarly, an increase in labor supply for a given level of labor demand results in higher unemployment and lower wages. From a statistical perspective, the lagged real wage gap functions as an error-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:

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

¹³Using 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.

¹⁴For a theoretical reference, in the canonical New Keynesian model described by Galí (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.

¹⁵For example, in the New Keynesian model described by Galí (2015) in Chapter 7, the real wage gap influences wages through labor demand only.

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.¹⁶ The equation suggests that a higher demand for goods and services results in a greater demand for labor, which, given a constant level of labor supply, increases the employment gap. Conversely, a larger real wage gap is positively associated with a higher labor supply. For a constant level of labor demand, this reduces the employment gap. As before, v_t^n explains the residual variation of the employment gap, and is modeled 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.

4. Selection of Priors

The system comprises 30 parameters that need to be estimated. It also includes 17 unobservable endogenous variables. Each of the four observable variables has 114 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.

4.1 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.¹⁷ It is important to emphasize 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

¹⁶For a theoretical reference, in the canonical New Keynesian model described by Galí (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.

¹⁷Note that, at an annual frequency, this is equivalent to seven quarterly observations.

Table 2. Priors for Shocks

	(1) π_t^p	(2) π_t^w	(3) Δn_t	(4) Δy_t
$SD(\varepsilon_t^x)$	0.217 (0.018)***	0.277 (0.030)***	0.200 (0.029)***	0.562 (0.077)***
$SD(e_t^x)$	0.081 (0.007)***	0.105 (0.008)***	0.072 (0.010)***	0.211 (0.027)***
$\frac{SD(\varepsilon_t^x)}{SD(e_t^x)}$	2.669 (0.235)***	2.632 (0.264)***	2.778 (0.365)***	2.660 (0.290)***
Observations	110	110	110	110
Note: The table provides the results from a state-space estimation, as explained in Subsection 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 percent, 5 percent, and 10 percent levels, respectively.				

trend. Next, within the framework of a state-space representation, an observation equation is defined as follows:

$$x_t = \ddot{x}_t + \varepsilon_t^x, \quad (7)$$

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

$$\ddot{x}_t = \eta^x \ddot{x}_{t-1} + \tau_t^x, \quad (8)$$

where τ_t^x is unobservable and follows a first-order autoregressive process with a disturbance denoted by e_t^x .¹⁸ 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 1 and 2 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} .

¹⁸The 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 .

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 2.7 (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 of 30 parameters instead of 33.

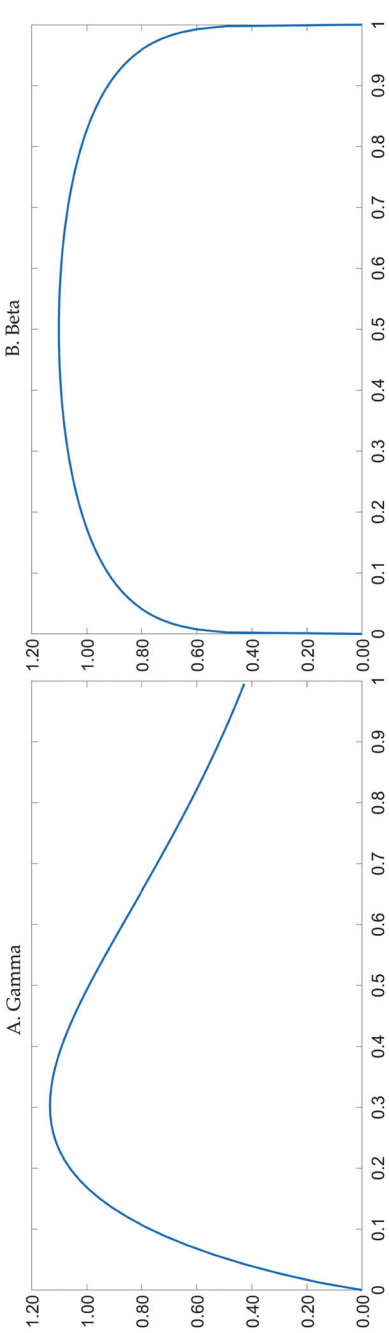
4.2 Elasticities

Turning to sensitivities, they are more likely to fall within the interval of zero to one. 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 parameterization 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 zero and one. Panel A of Figure 2 displays the shape of this distribution.¹⁹

For parameters bounded between zero and one, 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

¹⁹While the gamma distribution is not constrained on the right, only the zero-to-one interval is plotted for clarity.

Figure 2. Prior Distributions



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.

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.

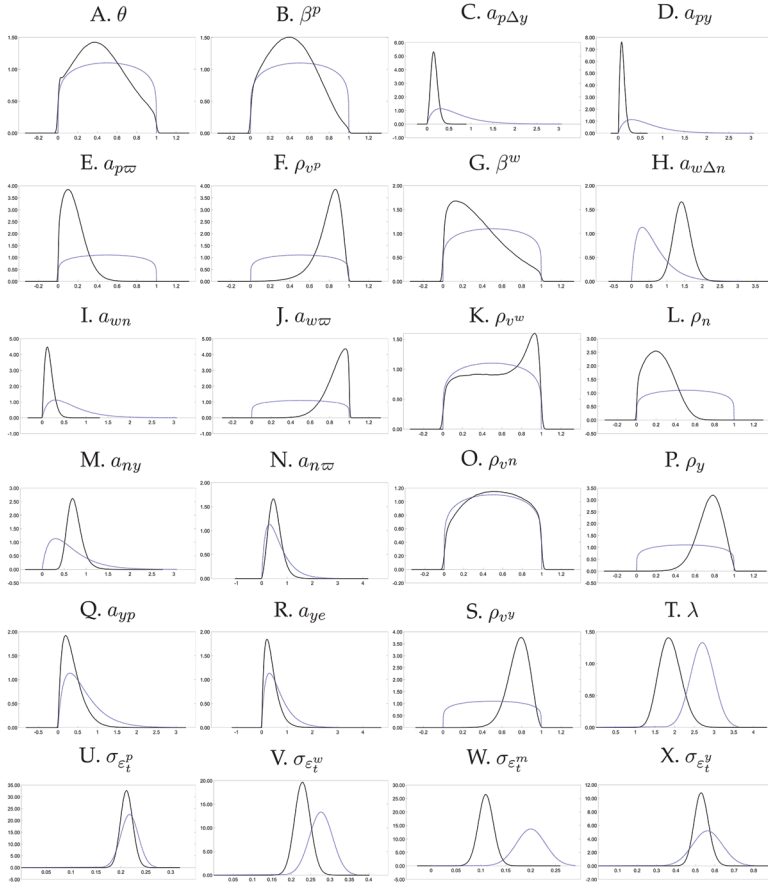
4.3 Long-Run Growth

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 $\sqrt{2} \cos(j(t - 0.5)/T)$ for $j = 1, \dots, 12$. 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 output stands at 0.057, with an associated standard error of 0.013 (statistically significant at 1 percent). These estimates serve as priors for σ_χ with $N \sim (0.057, 0.013)$. The estimated persistence parameter is 0.988 with a corresponding standard error of 0.005. These estimates are used as priors for ρ_χ with $N \sim (0.988, 0.005)$.

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 50 million draws, with an acceptance rate of 33 percent. After discarding the first 25 million draws, the convergence diagnostics signal convergence of the chain. The estimation procedure is executed using Dynare (Adjemian et al. 2022).

5. Estimation Results

The Dynare identification toolbox is utilized to verify the identification of parameters in the model calibrated at the mode. The three built-in tests reveal that all parameters are identified in the Jacobian of the (i) steady-state and reduced-form solution matrices; (ii) mean and spectrum (Qu and Tkachenko 2012); and (iii) first two moments (Iskrev 2010). However, the data sample used for estimation is notably short, especially considering the

Figure 3. Posterior Distributions

Note: The figure illustrates the prior and posterior distributions. The prior distribution is presented by the solid black line, while the posterior distribution is presented by the dotted blue line.

number of parameters and unobservable variables that require estimation. Consequently, in certain instances, some parameters are weakly identified (see Figure 3). Further investigation is necessary to address these limitations. Nonetheless, the impulse response functions and the historical shock decomposition appear reasonable, suggesting that the estimated parameters are largely plausible.

5.1 *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.²⁰ 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 $\Delta\bar{y} = 1.34$ percent, while the growth rate of employment is approximately $\Delta\bar{n} = 0.86$ percent. From these estimates, per capita output growth rate in the steady state is deduced to be around $\Delta\bar{y} - \Delta\bar{n} = 0.47$ percent. Consequently, the growth rate of real wages is $\Delta\bar{w} = 0.47$ 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 $\bar{\pi}^w = 2.47$ percent.

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 0.47, 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 47 basis points. The estimated parameter also

²⁰For conciseness, these estimates are not presented but are available upon request.

Table 3. Posterior Estimation of Parameters

	Distr.	Prior		Posterior				
		Mean	St. Dev.	Mode	Mean	St. Dev.	5 Pct.	95 Pct.
θ	Beta	0.500	0.273	0.465	0.434	0.309	0.000	0.786
β^p	Beta	0.500	0.273	0.403	0.419	0.358	0.023	0.751
$a_p\Delta y$	Gamma	0.644	0.469	0.147	0.167	0.076	0.041	0.285
a_{py}	Gamma	0.644	0.469	0.070	0.099	0.054	0.012	0.179
$a_{p\overline{w}}$	Beta	0.500	0.273	0.142	0.162	0.132	0.000	0.309
ρ_{v^p}	Beta	0.500	0.273	0.812	0.787	0.137	0.603	0.977
β^w	Beta	0.500	0.273	0.118	0.361	0.255	0.000	0.726
$a_w\Delta n$	Gamma	0.644	0.469	1.419	1.431	0.244	1.029	1.830
a_{wn}	Gamma	0.644	0.469	0.139	0.164	0.105	0.016	0.301
$a_{w\overline{w}}$	Beta	0.500	0.273	0.945	0.853	0.117	0.697	1.000
ρ_{v^w}	Beta	0.500	0.273	0.928	0.551	0.110	0.125	0.991
ρ_n	Beta	0.500	0.273	0.233	0.238	0.202	0.003	0.432
a_{ny}	Gamma	0.644	0.469	0.620	0.740	0.153	0.473	0.995
$a_{n\overline{w}}$	Gamma	0.644	0.469	0.383	0.535	0.257	0.122	0.920
ρ_{v^n}	Beta	0.500	0.273	0.472	0.514	0.586	0.112	0.962
ρ_y	Beta	0.500	0.273	0.793	0.746	0.128	0.557	0.953
a_{yp}	Gamma	0.644	0.469	0.162	0.371	0.170	0.014	0.725
a_{ye}	Gamma	0.644	0.469	0.203	0.389	0.208	0.016	0.759
ρ_{v^y}	Beta	0.500	0.273	0.796	0.762	0.119	0.598	0.937

Note: The posterior distribution is obtained using the Metropolis-Hastings algorithm. The estimations are performed in Dynare with a single chain consisting of 50 million draws, an acceptance rate of 33 percent, and a 50 percent burn-in.

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 0.40, with a standard deviation of 0.36. 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 0.15 and a standard deviation of 0.08, 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 0.05. 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 toward 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 0.14, coupled with a standard deviation of 0.13. Finally, the persistence of price shocks is estimated at 0.81 with a 0.14 standard deviation.

In the wage equation, coefficient β^w reflects wage sensitivity to expected inflation, estimated at 0.12 with a standard deviation of 0.26. 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 1.42, with a standard deviation of 0.24, it suggests that employment gap variations can strongly affect 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, the $a_{w\varpi}$ parameter measures error correction and indicates the required wage adjustment in light of deviations from long-run equilibrium. Its estimated value is 0.95 with a standard deviation of 0.12. The estimate is considerably higher than the one for inflation, and the standard deviation at the mode is smaller, suggesting that error correction significantly influences

euro-area wage dynamics. Finally, the estimated persistence for wage shocks is quite significant at 0.93, with a standard deviation of 0.11, primarily reflecting developments toward the end of the sample.

Turning to labor demand, the employment gap demonstrates moderate persistence, with an estimated parameter of 0.23 and a standard deviation of 0.20. The sensitivity of the employment gap to the output gap, represented by the coefficient a_{ny} , is estimated at 0.62 with a standard deviation of 0.15. Meanwhile, the sensitivity to the real wage gap, captured by the coefficient $a_{n\varpi}$, is estimated at 0.38, accompanied by a standard deviation of 0.26. Additionally, the persistence of labor demand shocks is estimated at 0.47 with a standard deviation of 0.59.

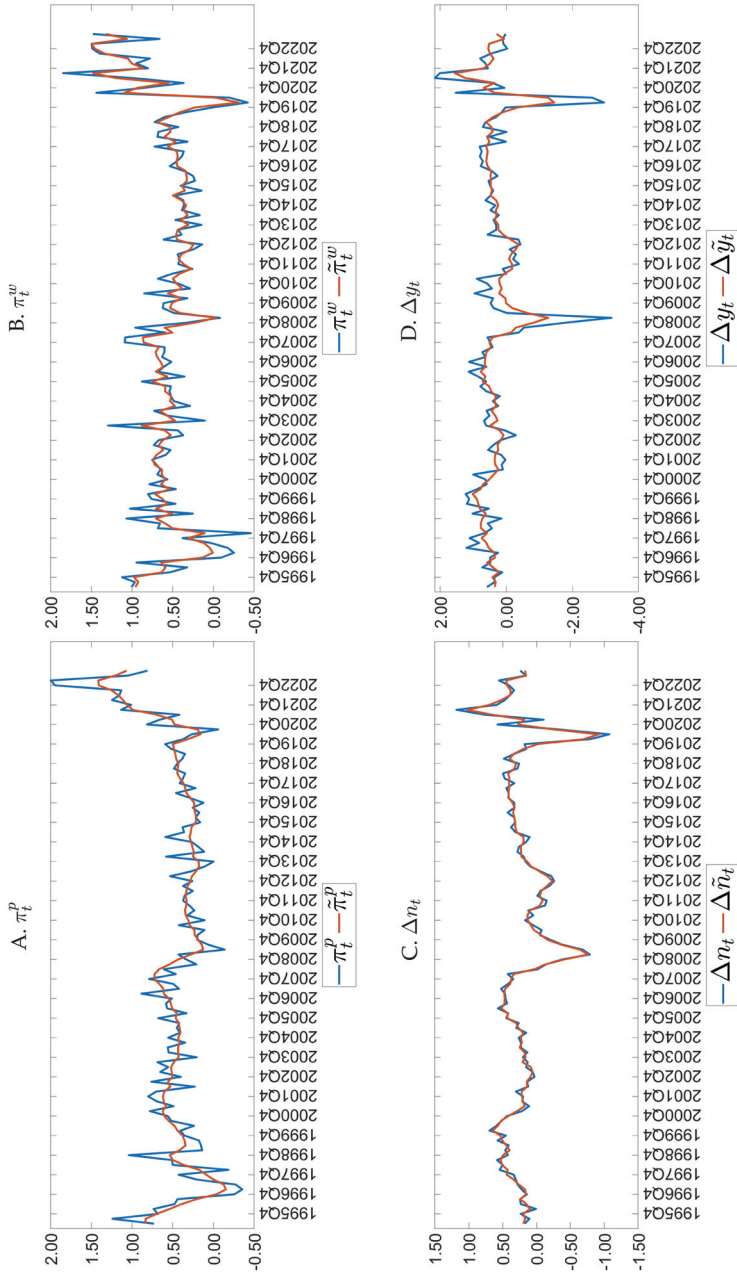
Lastly, aggregate demand demonstrates a high level of persistence, with a value of 0.80 and a standard deviation of 0.13. The persistence in demand is likely indicative of habit formation among consumers. The sensitivity of demand to current inflation, represented by a_{yp} , is estimated at 0.16 with a standard deviation of 0.17. Sensitivity to expected inflation, indicated by a_{ye} , stands at 0.20 with a standard deviation of 0.21. Demand shocks are also notably persistent, having a coefficient of 0.80 and a standard deviation of 0.12.

Table 4 summarizes 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, 0.21 (0.01), 0.22 (0.02), 0.11 (0.01), 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 0.29.

5.2 *Signal and Noise*

The blue line in Figure 4 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

Figure 4. Signal and Noise



Note: The figure displays the actual series along with its corresponding medium-run trend. The last in-sample observation is for 2023:Q3.

Table 5. Variance Decomposition

	e_t^p	e_t^w	e_t^y	e_t^n	e_t^x
$\tilde{\pi}_t^p$	54.5	3.4	42.1	0.1	0.0
$\tilde{\pi}_t^w$	43.6	6.9	44.0	4.6	1.0
$E_{t-1}\tilde{\pi}_t^p$	52.5	3.7	43.8	0.0	0.0
$\hat{y}_t$	0.1	0.0	99.9	0.0	0.0
$\hat{n}_t$	0.7	1.0	98.1	0.2	0.0
$\widehat{\omega}_t$	23.0	40.2	34.8	2.0	0.0
Note: The table presents the variance decomposition of key macroeconomic variables, with parameters calibrated to the estimated mode.					

volatility compared to inflation. This difference primarily arises from the modeling 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.

6. Decompositions

6.1 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 54.5 percent of the variations. Following closely,

the demand shock explains 42.1 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 significantly by the price shock at 43.6 percent, while the demand shock accounts for 44.0 percent. The wage shock and labor demand shock play smaller roles, contributing 6.9 and 4.6 percent, respectively.

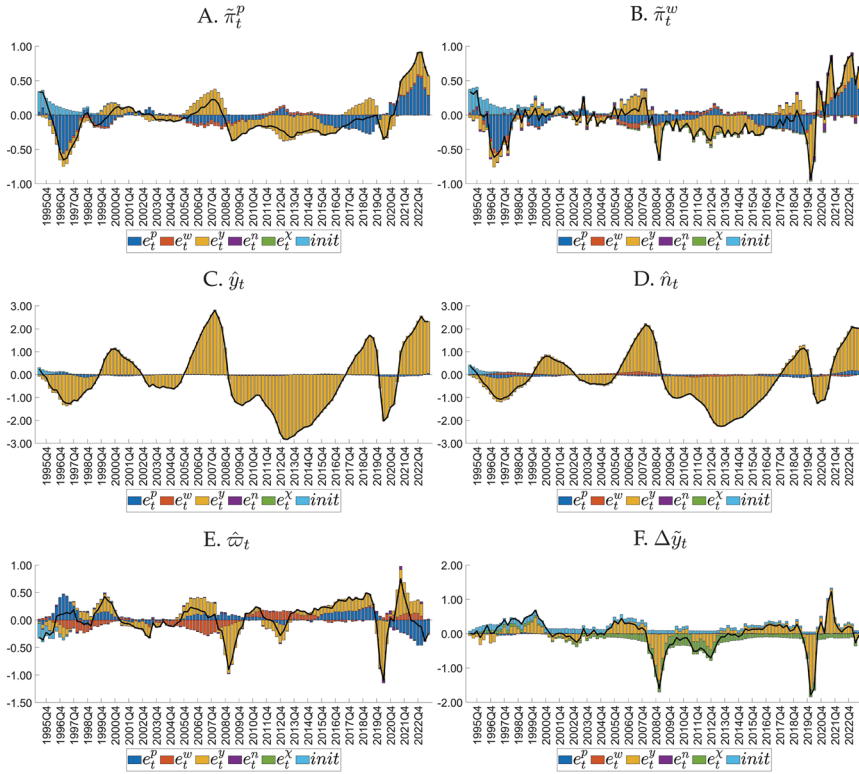
When examining the output gap and employment gap, both variables are almost entirely shaped by exogenous shifts in aggregate demand, with large contributions of 99.9 and 98.1 percent, respectively. The influences of other shocks on these variables are minimal. The real wage gap sees a wider influence from the exogenous factors. In particular, the wage shock accounts for 40.2 percent in wage variation, while the demand shock and price shock contribute around 34.8 and 23.0 percent, respectively. This underscores the pivotal roles these 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, while wage shocks explain more recent variation in the wage gap. Other shocks provide supplementary insights.

6.2 Shock Decomposition

Figure 5 presents the results of the historical shock decomposition over the sample period. The subsequent text focuses on the more recent period from 2019:Q1 to 2023:Q3.

Panel A presents the decomposition for medium-run inflation. From 2019:Q1 to 2019:Q3, inflation hovered just below the ECB target, and was on target on 2019:Q4. This period was marked by positive demand shocks counteracted by negative price shocks. Between 2020:Q1 and 2020:Q3, negative demand shocks pushed medium-run inflation well below its steady state. Starting in 2020:Q4, price shocks took hold and, combined with positive demand shocks, propelled medium-run inflation above the steady-state by 2021:Q2. Subsequent to this, both price and demand shocks have been driving inflation upward.

Figure 5. Shock Decomposition

Note: The figure illustrates the historical shock decomposition of key economic variables. The last in-sample observation is for 2023:Q3. 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 $\bar{\pi}^w = 0.62$. Finally, the quarterly steady-state value for output growth compared to the previous quarter is $\Delta \bar{y} = 0.33$, while the corresponding value for employment growth is $\bar{n} = 0.22$.

Panel B details the decomposition for the medium-run growth rate of nominal wages. Starting in 2019:Q1, there was a declining trend in the wage growth, primarily attributed to price shocks. In 2020:Q1, a sharp decline in wage growth occurred, largely influenced by demand shocks. From 2021:Q2, 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 2019:Q1 and 2019:Q4, demand shocks kept the gaps positive. However, the stretch from 2020:Q1 to 2021:Q1 was dominated by negative shocks, keeping both gaps negative. From 2021:Q3 onward, 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 2019:Q4 to 2020:Q3, negative demand shocks shifted the gap to negative territory. Between 2021:Q1 and 2022:Q1, 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).

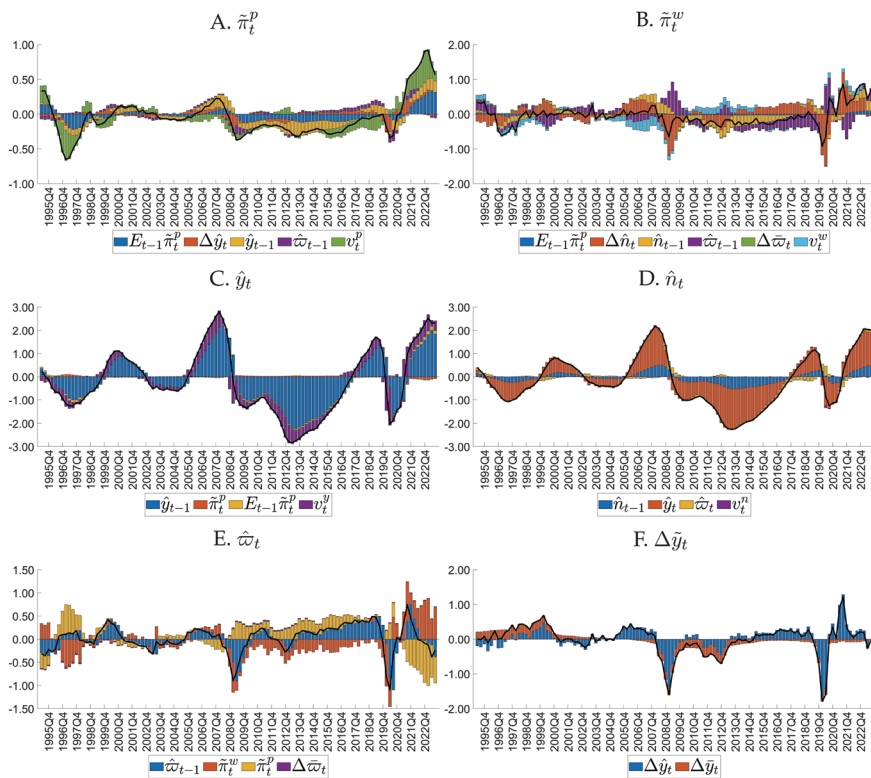
While this analysis is informative, it does not provide deep insights into factor contributions. For example, the price shock affects inflation, inflation expectations, and the wage gap. The current decomposition does not explain how each variable is associated with the dynamics of the primary variables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

6.3 Factor Decomposition

Figure 6 presents the results of the factor decomposition over the sample period. While the factor decomposition is informative, it is

A. $\tilde{\pi}_t^p$

B. $\tilde{\pi}_t^w$



important to recognize that all factors are interrelated. The subsequent text focuses on the more recent period from 2019:Q1 to 2023:Q3.

Panel A shows the results of the decomposition for medium-run inflation. The period spanning from 2019:Q1 to 2019:Q4 was largely characterized by a positive output gap, positive real wage

gap, and the recovery of inflation expectations toward 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 annualized medium-run inflation reaching close to 2 percent in 2019:Q4. The outbreak of the pandemic in 2020 brought about significant changes. In 2020:Q1 and 2020:Q2, a sharp contraction in aggregate demand and falling inflation expectations led inflation to dive below its steady-state value. From 2020:Q4, 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 labor market was tight, characterized by a positive employment gap. This had a favorable 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 downward from its steady-state value. The pandemic then induced a sharp employment drop, which in turn suppressed wage growth. From 2021:Q2 onward, labor 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 2021:Q2 to 2022:Q1. From 2022:Q2 onward, the upward corrective pressure from the negative real wage gap, labor 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 1.5 percent. The periods 2020:Q1 and 2021:Q2 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 2020:Q2 through to 2021:Q1. As the economy began to recover from the pandemic, a series of positive demand shocks propelled the output gap back into positive territory from 2021:Q3 onward. Coupled with the significant own persistence, the output gap has now surpassed its pre-pandemic level, reaching a value of 2.3 percent in 2023:Q3.

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

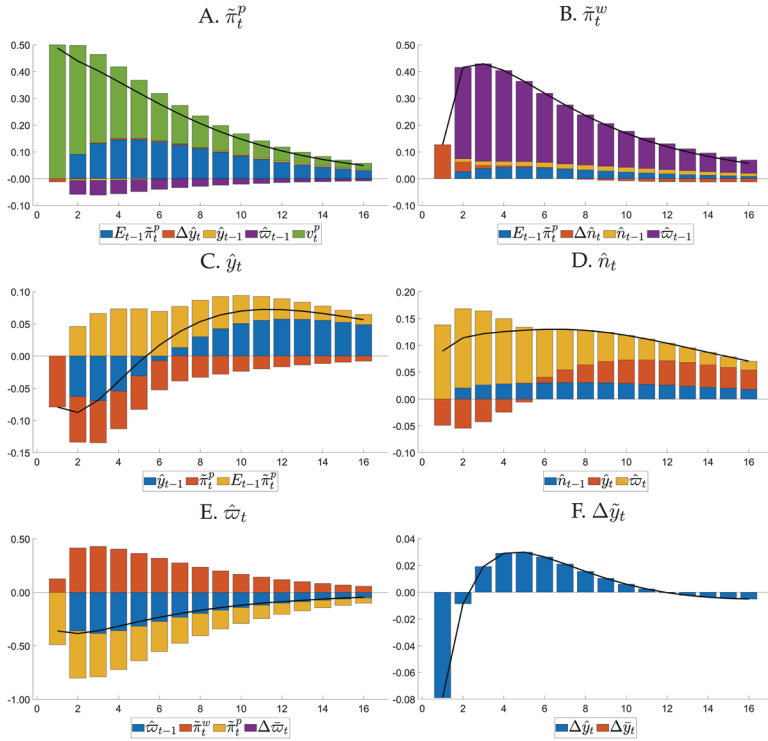
Panel E illustrates the decomposition of the real wage gap. By its design, inflation exerts downward pressure on the real wage gap, whereas growth in nominal wages tends to elevate it relative to the long-run trend. The year 2019 was characterized by a positive gap, signifying that real wages exceeded their long-run trend. Nevertheless, there was an overarching downward trend during this time. Between 2020:Q1 and 2020:Q3, the real wage gap declined into negative territory. It then remained close to its long-run equilibrium from 2020:Q4 to 2021:Q1 before climbing back into positive territory, peaking in 2021:Q3. Since then, the trend of the real wage gap has been on a downward trajectory, turning negative in 2022:Q2 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 subpar long-term growth rate of the output.

7. 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.²¹

²¹The remaining responses are available from the author upon request.

Figure 7. Response to a Shock e_t^p of Magnitude $\bar{\pi}^p$ 

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 $\bar{\pi}^w = 0.62$. Finally, the quarterly steady-state value for output growth compared to the previous quarter is $\Delta\bar{y} = 0.33$, while the corresponding value for employment growth is $\bar{n} = 0.22$.

7.1 A Price Shock

Figure 7 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 labor demand equation, as it enters the equation contemporaneously. Increased labor 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.

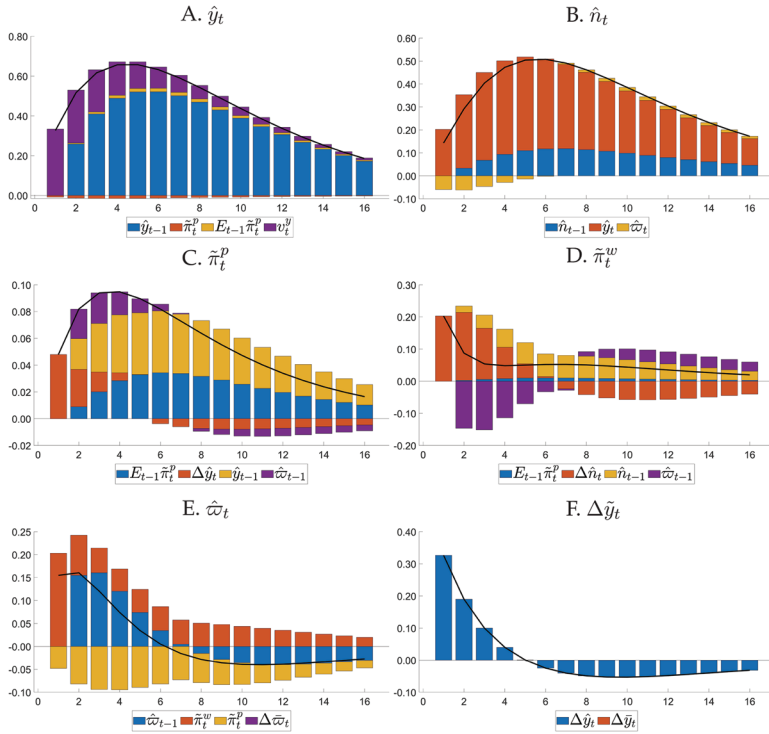
Following the initial shock, the variables begin a gradual adjustment back to their steady-state values. In panel A, the persistence of the shock maintains inflation above its steady-state value for an extended duration. Even as the influence of the shock wanes, inflation expectations rise, sustaining 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 dominates pressure from expected inflation. Over time, however, these factors largely neutralize each other.

Panel D depicts the employment response. The dynamics here are chiefly governed by the real wage gap. Since a negative real wage gap corresponds to diminished labor supply for a given labor demand, it raises the employment gap. Meanwhile, a decline in aggregate demand, and the associated reduction in labor 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

Figure 8. Response to a Shock e_t^y of Magnitude $\Delta\bar{y}$ 

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 $\bar{\pi}^w = 0.62$. Finally, the quarterly steady-state value for output growth compared to the previous quarter is $\Delta\bar{y} = 0.33$, while the corresponding value for employment growth is $\bar{n} = 0.22$.

state. Lastly, the dynamics of the medium-run growth rate are solely influenced by the cyclical behavior of the output gap (panel F).

7.2 A Demand Shock

Figure 8 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 enters

the demand equation, the output gap immediately rises by about 0.3 percentage points. This causes an instantaneous increase in both inflation and labor demand since the output gap affects inflation and labor demand contemporaneously. The rise in labor 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 labor demand, though to a lesser extent than the increase in the output gap itself. The response also reveals a slight persistence in labor 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 toward the end of the response period, as the gap itself turns negative.

Panel D displays the breakdown of the wage response. Following the initial shock, the dynamics are dominated by tight labor 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. Toward 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 labor market effectively disappears. Finally, inflation expectations play a negligible role in wage dynamics following a demand shock.

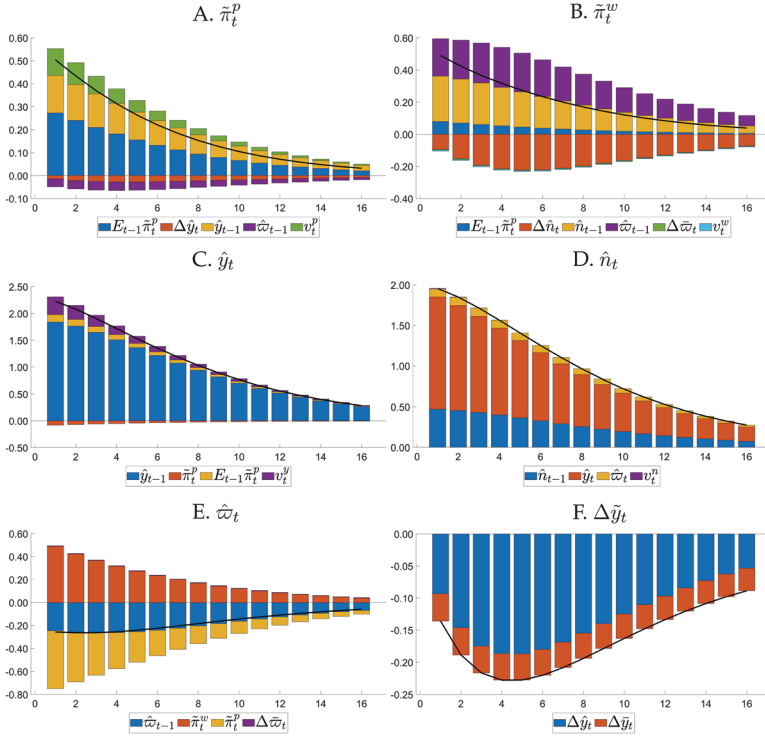
Panel E presents findings related to the real wage gap. Like before, this breakdown relies on the real wage gap identity. After its initial surge, the factor decomposition shows that the initial dominance of wage growth diminishes after the first two quarters. The subsequent dynamics highlight a gradual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

8. Forecasting Out of Sample

8.1 *Forecast Decomposition*

Figure 9 presents forecasts of key variables derived from the model calibrated with parameters set at the mode. The last in-sample observation is for 2023:Q3. 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 toward the steady state, irrespective of potential exogenous shocks that could arise, whether they are favorable or unfavorable.

Panel A portrays the forecast decomposition for inflation from 2023:Q4 to 2027:Q3. 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 relative to the previous quarter. The point estimate for 2023:Q4 is 1.0 percent. Combining this 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 5.2 percent. Mean predictions for 2024, 2025, and 2026 are 3.8, 2.9, and 2.5 percent, respectively. Inflation expectations, followed by 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 4.8, 3.4, 2.7, and 2.3 percent for the years 2023 to 2026, respectively.

Figure 9. Out-of-Sample Forecasts

Note: The figure illustrates the out-of-sample forecast for key economic variables. The last in-sample observation is for 2023:Q3. 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 $\tilde{\pi}^p = 0.5$. For wage growth, the quarterly steady-state value relative to the previous quarter is $\tilde{\pi}^w = 0.62$. Finally, the quarterly steady-state value for output growth compared to the previous quarter is $\Delta\bar{y} = 0.33$, while the corresponding value for employment growth is $\bar{n} = 0.22$.

Panel B provides the forecast decomposition for wage growth between 2023:Q4 and 2027:Q3. 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 relative to the previous quarter. The point estimate for 2023:Q4 is 1.1 percent. Combining this with medium-run wage growth values from the beginning of 2023, the year-on-year average forecast

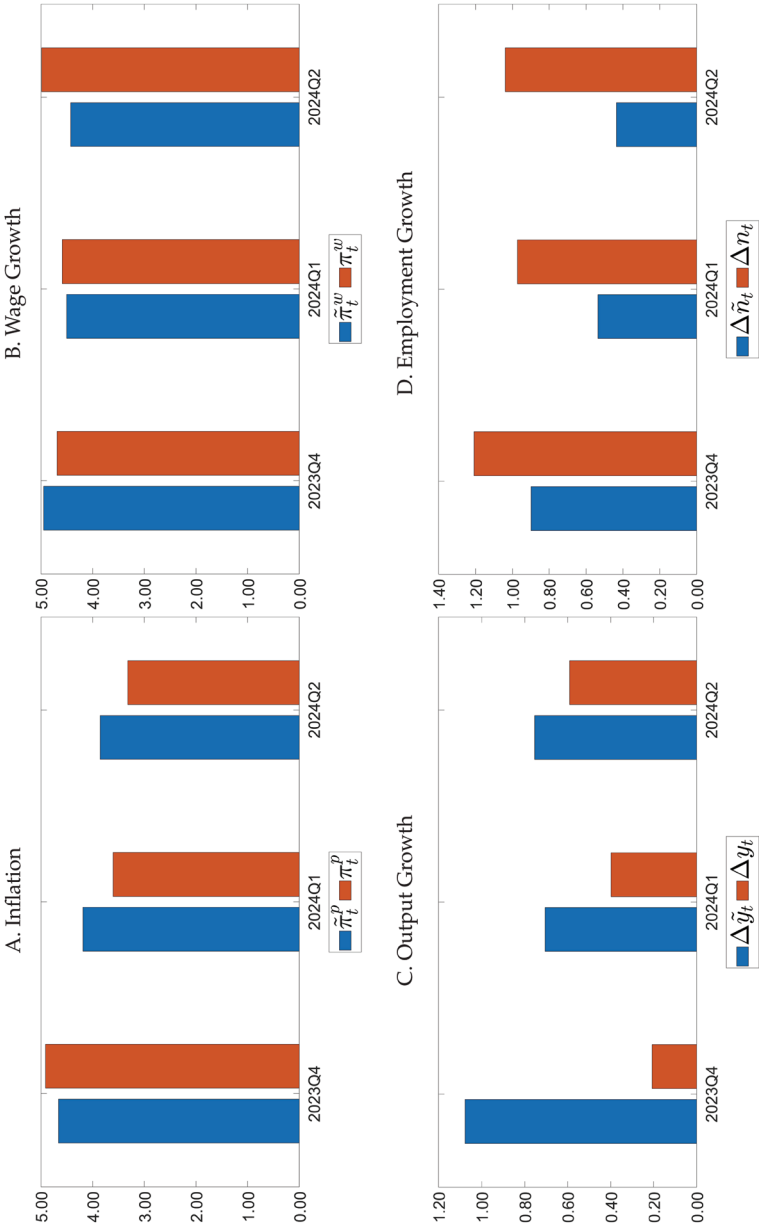
for wage growth in 2023 is 5.3 percent. For 2024, 2025, and 2026, forecasts are 4.3, 3.5, and 3.0 percent, respectively. The forecast dynamics mainly stem from the corrective force of the real wage gap, with labor market tightness also playing a key role in the initial few quarters. Inflation expectations rank third. Meanwhile, the projections for each quarter, when compared to the same quarter of the previous year, are 5.1, 3.9, 3.3, and 2.9 percent for the years 2023 through 2026, respectively.

Panel C depicts the forecast decomposition for the output gap from 2023:Q4 to 2027:Q3. The output gap at the beginning of the forecast period is approximately 2.2 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 2.0 percent at the beginning of the period, underlining labor 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 approximately negative 0.3 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 13 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 subpar long-run growth rate of output.

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 difficult to align with actual data. This might result in perceived inaccuracies in the forecast, even if the medium-run trend is captured relatively well. Nevertheless, Figure 10 provides a glance at the out-of-sample performance of

Figure 10. Out-of-Sample Forecast Performance



Note: The figure illustrates the out-of-sample forecast for key economic variables alongside their actual values, with forecasts performed as of 2023:Q3. $\tilde{\pi}_t^p$ represents the quarter-on-quarter forecast for medium-run inflation, while π_t^p presents the actual value of headline inflation. $\tilde{\pi}_t^w$ represents the out-of-sample quarter-on-quarter forecast for medium-run wage growth, while π_t^w presents the actual value of wage growth. $\Delta \tilde{y}_t$ represents the out-of-sample quarter-on-quarter forecast for the medium-run output growth rate, while Δy_t presents the actual value of the output growth rate. Finally, $\Delta \tilde{n}_t$ represents the out-of-sample quarter-on-quarter forecast for the medium-run employment growth rate, while Δn_t presents the actual value of the employment growth rate.

the forecasts. While the estimations are based on sample data from 1995:Q2 to 2023:Q3, data for 2023:Q4–2024:Q2 are also available.²²

Panels A for inflation and B for wage growth show that the three-quarter out-of-sample performance of the forecast is quite satisfactory, even though the comparison is between the medium-run trend and the reported headline values. For the growth rate of output, the discrepancy is larger, as can be seen in panel C. In particular, the projected medium-run growth rate of output is higher than the reported value of output growth rate. Interestingly, the reported value seems to be increasing while the medium-run value of the output growth rate shows a bit of decline, stabilizing around a somewhat similar value as the realized value of the output growth rate. Finally, panel D shows that the medium-run growth rate of employment is relatively stable, though some decline is visible. A somewhat similar pattern can be observed for the realized growth rate of employment, yet the discrepancy between the medium-run trend and the realized value is somewhat large. This, however, is not surprising, as Figure 6 shows that the medium-run trend is much smoother than the corresponding headline number, with clear patterns of misalignment in certain cases.

8.2 Discussion

8.2.1 On Projections

The ECB and Eurosystem staff continuously produce macroeconomic forecasts. Panel A of Figure 11 provides these projections for inflation together with the forecasts generated by this framework. ECB December 2023 projections reveal that inflation in the euro area, measured using the GDP deflator, is anticipated to average 5.6 percent in 2023.²³ This rate is expected to decline to 2.9 percent in 2024, further receding to 2.5 percent by 2025, and is at 1.9 percent in 2026. Panel B displays projections for wage growth.

²²At the time of writing, data for the deflator and compensation per employee are available until 2024:Q1. However, it is possible to construct synthetic series and expand them for an additional quarter using other highly correlated variables for which the data are available.

²³The ECB December 2023 projections were selected to ensure maximum comparability with the data used in this analysis.

Figure 11. Comparison



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 illustrates annualized inflation expectations at a quarterly frequency. Panel D offers annualized projections of model-generated inflation expectations, complemented by the annual inflation forecast. Panel E displays the annual output gap series generated by the model, alongside the annual output gap series from the IMF World Economic Outlook data set. 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 the World Development Indicators data set.

For 2023, 2024, 2025, and 2026 the growth rate of nominal wages is expected to be 5.3, 4.6, 3.8, and 3.3. 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 annualized expectations at a quarterly frequency for model-generated inflation 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. Running a simple ARIMA(1,0,0) on the series yields a persistence coefficient of 0.97 for the model-generated expectations. These estimates underscore the previously mentioned stickiness of expectations. Consequently, the sizable and enduring shock that occurred suggests a gradual decrease in expectations, leading to prolonged high inflation, as shown in panel D.

8.2.2 *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 modeling this residual variation by analyzing 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 implicitly incorporated into the gap itself. Given the significant impact of fiscal policy on aggregate demand, its modeling could provide a more nuanced understanding of inflationary trends and their underlying causes. For instance, while fiscal stimulus has been substantial in both the euro area and the U.S., it has arguably been stronger in the latter. This suggests that, compared to studies such as Bernanke and Blanchard (2023), the role of fiscal policy as a driver of inflation may be somewhat smaller in the euro-area context. Nonetheless, integrating fiscal policy could help improve forecasts. Prior work suggests that fiscal shocks can have non-negligible effects on inflation. For example, Cevik and Miryugin (2023) find that a one-standard-deviation decline in the budget balance-to-GDP ratio is associated with a

cumulative increase in headline inflation of around 0.7 percentage points over the medium run. Additionally, due to the 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 reestimation is essential, possibly employing a rolling window to prioritize 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 International Monetary Fund, as shown in panel E of Figure 11. The employment gap series resemble the demeaned unemployment rate, as shown in panel F of Figure 11. Combined, these lend credence to the plausibility of the results. Nevertheless, it is essential to recognize 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

9. 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, this paper provides an empirical framework and analysis of the interrelations among inflation, wages, employment, and output, with a focus on the euro area.

²⁴For a discussion on the estimation of dynamic stochastic general equilibrium (DSGE) models, see Blanchard (2016).

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 suggests 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 labor markets.

Regarding inflation expectations, the estimates underscore their stickiness. Against this backdrop, the significant and persistent shock initially pointed to a gradual decline in expectations, raising concerns about a prolonged period of elevated inflation. However, the monetary policy response has been notably sharp, and inflation now appears to be gradually returning to target. This underscores the importance of timely and decisive monetary interventions in managing inflation expectations.

Further extensions of the framework are warranted in at least two dimensions. Firstly, recognizing that fiscal policy plays a 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 policymaking 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 by²⁵

$$w_t - w_{t-1} = E p_t - p_{t-1} - \alpha(E p_{t-1} - p_{t-1}) + \beta(x_t - \alpha x_{t-1}) + z_t^\varpi. \quad (\text{A.1})$$

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

$$\pi_t^w = E \pi_t^p - \alpha(E \pi_{t-1}^p - \pi_{t-1}^p) + \beta \Delta x_t + \beta(1 - \alpha)x_{t-1} + z_t^\varpi. \quad (\text{A.2})$$

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

$$p_t - p_{t-1} = (w_t - w_{t-1}) + (z_t^p - z_{t-1}^p), \quad (\text{A.3})$$

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:

$$\pi_t^p = \pi_t^w + \Delta z_t^p. \quad (\text{A.4})$$

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

$$E p_t - p_{t-1} = \delta \pi_t^* + (1 - \delta)(p_{t-1} - p_{t-2}), \quad (\text{A.5})$$

while the long-run expectations are expressed through

$$\pi_t^* = \gamma \pi_{t-1}^* + (1 - \gamma)(p_{t-1} - p_{t-2}). \quad (\text{A.6})$$

²⁵The equation is derived by assuming that the level of wages is determined according to $w_t = E p_t + \varpi_t^A + \beta x_t$, 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 labor 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.

The system presented in Subsections 3.1 to 3.4 differs from the framework of Bernanke and Blanchard (2023) along several key dimensions. In terms of time frame, 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 time frame. 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 modeled 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 Federal Reserve. In contrast, inflation expectations in the current paper are modeled 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 toward 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 modeled 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 modeled 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 Galí 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.

References

- Adjemian, S., H. Bastani, M. Juillard, F. Karamé, F. Mihoubi, W. Mutschler, J. Pfeifer, M. Ratto, N. Rion, and S. Villemot. 2022. “Dynare: Reference Manual, Version 5.” Dynare Working Paper No. 72, CEPREMAP.

- Benigno, P., and G. Eggertsson. 2023. "It's Baaack: The Surge in Inflation in the 2020s and the Return of the Non-Linear Phillips Curve." NBER Working Paper No. 31197.
- Bernanke, B., and O. Blanchard. 2023. "What Caused the U.S. Pandemic-Era Inflation?" Working Paper No. 23-4, Peterson Institute for International Economics.
- Blanchard, O. 2016. "Do DSGE Models Have a Future?" Policy Brief No. 16-11, Peterson Institute for International Economics.
- Bobeica, E., M. Ciccarelli, and I. Vansteenkiste. 2019. "The Link Between Labor Cost and Price Inflation in the Euro Area." ECB Working Paper No. 2235.
- Calvo, G. 1983. "Staggered Prices in a Utility-Maximizing Framework." *Journal of Monetary Economics* 12 (3): 383–98.
- Cevik, S., and F. Miryugin. 2023. "Never Different: Fiscal Policy Shocks and Inflation." IMF Working Paper No. 23/98.
- De Santis, R., and T. Tornese. 2023. "Energy Supply Shocks' Non-linearities on Output and Prices." ECB Working Paper No. 2834.
- Eser, F., P. Karadi, P. Lane, L. Moretti, and C. Osbat. 2020. "The Phillips Curve at the ECB." ECB Working Paper No. 2400.
- Gabaix, X. 2020. "A Behavioral New Keynesian Model." *American Economic Review* 110 (8): 2271–2327.
- Galí, J. 2015. *Monetary Policy, Inflation, and the Business Cycle: An Introduction to the New Keynesian Framework and Its Applications*. Second Edition. Princeton University Press.
- Galstyan, V. 2019. "Inflation and the Current Account in the Euro Area." Economic Letter No. 4, Central Bank of Ireland.
- . 2021. "Expectations, Unemployment and Inflation: An Empirical Investigation." *International Finance* 24 (3): 298–312.
- Gelman, A., and Y. Yao. 2021. "Holes in Bayesian Statistics." *Journal of Physics G: Nuclear and Particle Physics* 48 (1): Article 014002.
- Gertler, M., and J. Leahy. 2008. "A Phillips Curve with an Ss Foundation." *Journal of Political Economy* 116 (3): 533–72.
- Gonçalves, E., and G. Koester. 2022. "The Role of Demand and Supply in Underlying Inflation — Decomposing HICPX Inflation into Components." *Economic Bulletin* (European Central Bank) 7/2022.

- Hahn, E. 2020. "The Wage-Price Pass-Through in the Euro Area: Does the Growth Regime Matter?" ECB Working Paper No. 2485.
- Hansen, N.-J., F. Toscani, and J. Zhou. 2023. "Euro Area Inflation after the Pandemic and Energy Shock: Import Prices, Profits and Wages." IMF Working Paper No. 23/31.
- Harding, M., J. Lindé, and M. Trabandt. 2023. "Understanding Post-COVID Inflation Dynamics." *Journal of Monetary Economics* 140 (Supplement): S101–S118.
- Hyndman, R., A. Koehler, K. Ord, and R. Snyder. 2008. *Forecasting with Exponential Smoothing: The State Space Approach*. Springer Series in Statistics.
- Ireland, P. 2004. "Technology Shocks in the New Keynesian Model." *Review of Economics and Statistics* 86 (4): 923–36.
- Iskrev, N. 2010. "Local Identification in DSGE Models." *Journal of Monetary Economics* 57 (2): 189–202.
- Lane, P. 2022. "Inflation Diagnostics." *The ECB Blog*, November 25.
- Lo Bello, S., and E. Viviano. 2024. "Some Considerations on the Phillips Curve after the Pandemic." Occasional Paper No. 842, Banca D'Italia.
- Lorenzoni, G., and I. Werning. 2023. "Wage Price Spirals." Manuscript, MIT.
- Mankiw, G., and R. Reis. 2002. "Sticky Information versus Sticky Prices: A Proposal to Replace the New Keynesian Phillips Curve." *Quarterly Journal of Economics* 117 (4): 1295–1328.
- Müller, U., and M. Watson. 2015. "Low-Frequency Econometrics." NBER Working Paper No. 21564.
- Qu, Z., and D. Tkachenko. 2012. "Identification and Frequency Domain Quasi-Maximum Likelihood Estimation of Linearised Dynamic Stochastic General Equilibrium Models." *Quantitative Economics* 3 (1): 95–132.
- Shapiro, A. 2022. "Decomposing Supply and Demand Driven Inflation." Working Paper No. 2022-18, Federal Reserve Bank of San Francisco.
- Smets, F., and R. Wouters. 2007. "Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach." *American Economic Review* 97 (3): 586–606.

Werning, I. 2022. "Expectations and the Rate of Inflation." NBER Working Paper No. 30260.

Woodford, M. 2003. *Interest and Prices: Foundations of a Theory of Monetary Policy*. Princeton, NJ: Princeton University Press.