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Abstract

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JEL Classification: C51, E31, E47, E52

Keywords: Phillips curve, Non-linearities, Inflation, Monetary policy

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Monetary policy in the Euro Area, when Phillips curves ... are curves*

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July 24, 2025

Abstract

We study monetary policy where the price and wage Phillips curves exhibit true curvature. To this end, we propose a New Keynesian (NK) model featuring endogenous adjustment of price and wage setting frequencies, moving beyond the quasi-linear structure of the standard nonlinear NK Phillips curves (NKPC). Using euro area data spanning 1999Q1 to 2024Q4, we estimate and simulate the non-linear model. We then study the recent inflation surge and the implications of state-dependent prices and wages for monetary policy in the estimated non-linear model. Unlike conventional models, our framework does not primarily explain inflation dynamics by exogenous supply shocks. Instead, the impact of shocks on inflation depends on their timing, size, and the business cycle. Consequently, the inflation-output stabilization trade-off faced by monetary policy is state-dependent. For example, monetary policy is more effective in curbing inflation, and supply shocks have larger effects during periods of high inflation.

***Keywords*:** New Keynesian Phillips Curve, non-linearity, inflation, monetary policy.
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'The relation between unemployment and the rate of change of wage rates is therefore likely to be highly non-linear.'

(Phillips, 1958, p. 283)

1 Introduction

The 2021-2022 surge in inflation across advanced economies has renewed interest in understanding the mechanisms driving price and wage dynamics. Inflationary pressures have led not only to higher consumer prices but also to a rise in wage inflation, reflecting changes in firms' and workers' price- and wage-setting behavior. Notably, accelerating inflation has been accompanied by more frequent price and wage adjustments, suggesting a partly state-dependent mechanism and raising concerns among policymakers about second-round effects and the strength of wage-price interactions. Despite these concerns, recent data suggest that both the European Central Bank (ECB) and the Federal Reserve (Fed) have successfully navigated a *"soft landing"*, stabilizing inflation without triggering a deep recession. Developing a better theoretical and empirical understanding of these events is essential to assess the trade-offs monetary policy is facing.

However, the standard New Keynesian (NK) model, widely used for monetary policy analysis, lacks a mechanism to generate state-dependent dynamics in price and wage setting. It typically relies on time-dependent pricing assumptions, which assume that price and wage adjustments occur at a constant probability, independent of economic conditions (e.g., Calvo, 1983). Once estimated, NK models commonly imply relatively flat and state-invariant price and wage Phillips curves, suggesting that price and wage inflation dynamics are primarily driven by supply shocks, while demand shocks (and monetary policy) affect inflation only marginally (see, e.g., Fratto and Uhlig, 2020). Such environments predict a large and state-invariant stabilization trade-off limiting monetary policy effectiveness. Reducing inflation requires a substantial contraction in output and a *"soft landing"* is unlikely.

Against this background, the paper makes two main contributions: theoretically, we develop a NK model in which the price and wage resetting frequency changes endogenously with the state of the business cycle; empirically, we take these non-linearities to euro area data, by estimating the model with a non-linear method.

Regarding the first contribution, we build on Gasteiger and Grimaud (2023), who propose a novel mechanism to introduce state-dependent price-setting behavior in an otherwise standard NK model. In their model, the price-setting frequency is endogenous. Firms update prices based on a discrete choice process that weighs expected costs and benefits, capturing the extensive margin of price setting. When expected benefits exceed costs, firms are more likely to adjust prices optimally. We expand their approach by considering state-dependent wage setting to allow both price- *and* wage-setting frequencies to vary endogenously with economic conditions. The fraction of firms and unions that re-set their prices is based on a cost-benefit analysis, where adjustment frequencies increase when inflation is high. The empirical relevance of our proposed mechanism is supported by recent findings. Gödl and Gödl-Hanisch (2024) document that wage-setting frequencies increase during periods of elevated inflation. Similarly, it has been established that firms adjust prices more frequently during an inflation surge (see, e.g., Gautier et al., 2025; Montag and Vallenas, 2023).

State-dependent adjustment frequencies give rise to non-linear price and wage Phillips curves. Consequently, the NK model exhibits state-dependent Phillips curve slopes and a stabilization trade-off that varies with economic conditions. Thereby we address a key shortcoming of the standard NK model, i.e., its structural relationship between inflation and real activity remains nearly linear, even in its non-linear form. This quasi-linearity limits the model's ability to generate state-dependent inflation dynamics and stabilization trade-off. However, empirical evidence suggests that this trade-off is, in fact, state-dependent and was historically low during the last inflation surge (Forbes et al., 2025; Zlobins, 2024).

By embedding state-dependent nominal rigidities, our model provides a channel through which new-Keynesian Phillips curves can exhibit such non-linearities. In the paper, we begin by building intuition for the implications of this mechanism using a small-scale version of the model. We then show how various aspects of the model become state-dependent, including the slopes of the wage and price Phillips curves, the impulse response functions (IRFs) to the shocks, and the stabilization trade-off faced by monetary policy. Then, we quantitatively assess the role of this non-linearity in explaining the recent inflation surge using euro area data. This is the paper's main contribution.

Since the focus of the paper is on the non-linearity implied by state-dependent price *and* wage setting frequencies, estimating a linearized model – the usual practice in the NK literature – would fail to capture these effects, as it imposes an artificial symmetry between upward and downward adjustments in prices and wages. We therefore move beyond standard perturbation methods and adopt a numerical solution that preserves the richness of the propagation mechanisms of our framework. Specifically, we follow the approach of Adjemian and Juillard (2024); Sahuc et al. (2025), an updated implementation of the extended path method originally proposed by Fair and Taylor (1983), to simulate the nonlinear model using MIT shocks and assume no aggregate uncertainty. Specifically, we employ an inversion filter that treats the nonlinear model itself as the data-generating process. This allows for direct statistical evaluation against four macroeconomic time series from 1999Q1 to 2024Q4. Our approach follows the tradition of structural estimation pioneered by Smets and Wouters (2007). Then, using Bayesian techniques, we estimate the structural parameters of the model and identify the main driving forces of inflation dynamics in the euro area.

Finally, the paper uses the estimated quantitative model to examine the implications of state-dependent price *and* wage setting for monetary policy, specifically focusing on the recent inflation surge in the euro area. First, we examine how the stabilization trade-off faced by monetary policy changed during this episode. Second, we conduct counterfactual analyses to examine alternative monetary policy behavior in the recent inflation period, contributing to the debate about whether monetary policy should have "looked through" the inflationary shocks.

Our findings have important implications for monetary policy. First, our model interprets the recent inflation surge in the euro area as an episode of steepening price and wage Phillips curves. This steepening is driven by time-varying price- and wage-setting frequencies, which play a central role in shaping inflation dynamics. As a direct consequence, also the stabilization trade-off becomes state-dependent, meaning that the cost of disinflation in the euro area varies depending on macroeconomic conditions. Second, from a dynamic perspective, firms adjust prices faster than wages during the surge, with wages gradually catching up, resulting in a lagged yet persistent wage response. Third, with the benefit of hindsight, our analysis suggests that monetary policy could have responded more aggressively during the early stages of the inflation surge, with relatively low output costs. Fourth, our results indicate that the size of supply shocks is crucial in determining the appropriate policy response. Large cost-push shocks cannot be ignored, because state-dependent price- *and* wage-setting can quickly thrust inflation.

Our paper provides several new results. First, it highlights a new mechanism to study the interaction between state-dependent price- *and* wage-setting in shaping inflation dynamics within a DSGE framework. Second, our estimated quantitative model provides a more accurate account of recent euro area inflation dynamics by emphasizing the importance of this new mechanism. Third, our paper challenges the assumption of constant stabilization trade-offs in monetary policy analysis by demonstrating how these trade-offs vary with inflationary conditions. Finally, it offers new insights into the policy debate on the effectiveness of monetary policy in curbing inflation, especially in periods of high inflation.

To conclude, we propose a tractable method for incorporating non-linearities arising from state-dependent frequencies of price and wage adjustments in a non-linearly estimated NK-DSGE model. Given the significance of the recent inflationary episode in the Euro area data, our methodology should prove valuable for future structural macroeconomic studies on the Euro area.

Related literature. Our paper is obviously connected to the very large literature on state-dependent pricing. That literature flourished in the last two decades, given the availability of micro data on prices – less on wages. It generated several seminal contributions that enhanced our understanding of the distribution of price changes, its dynamics and drivers. To survey this literature – or cite all the relevant papers – is not feasible here, but Costain and Nakov (2024) provide a very recent and comprehensive survey on the topic. Of course, our modeling approach, based on Gasteiger and Grimaud (2023), cannot – and does not aim at – reproducing the distribution of price (or wage) changes. It provides a short-cut way to take into account some insights from this recent literature, and make them operational in estimating large NK models. Our approach, for example, does not feature the selection effect typical of the early menu cost state-dependent models (e.g., Golosov and Lucas, 2007). However, Costain and Nakov (2024) argue that the micro evidence seems inconsistent with the early basic menu cost models, motivating research to move towards a more general class of state-dependent models, in which the adjustment probability rises smoothly with the value of adjusting, implying a much weaker selection effect, and thus greater real effects of monetary policy. Our mechanism aims at capturing this smooth state-dependent behavior in adjusting frequencies. Moreover, state-dependent models, which match patterns from microdata, share many of the macro implications of the Calvo model (see again Costain and Nakov, 2024) – when the latter is accordingly recalibrated. However, the key difference identified by Costain and Nakov (2024) between the state-dependent models and the standard Calvo model is that the former imply rapid and flexible price changes in some circumstances, as for high inflation (Alvarez et al., 2019), for large shocks (Cavallo et al., 2024; Karadi and Reiff, 2019), making the Phillips curve slope state-dependent (Karadi et al., 2024).

Our mechanism should be seen as a way to capture all these effects, and hence, as complementary to this literature. While admittedly using a short-cut relative to a microfounded state-dependent model, we provide a tractable way to incorporate state-dependent price- *and* wage- setting into the standard model. "Tractable way" has a very precise meaning for us: a way to estimate a non-linear quantitative NK model with state-dependent price- *and* wage-setting with a non-linear method. This is particularly important as fully microfounded state-dependent models, while able to match the micro data, are still computationally quite far away from being incorporated in a non-linearly estimated NK model. To the best of our knowledge, this paper is the first one that includes state-dependent price- *and* wage-setting in a non-linear NK model, non-linearly estimated on aggregate euro area data, to provide policy analysis and data-contingent counterfactuals.

From this very same perspective, Blanco et al. (2024) is the closest paper to ours. They also propose a different mechanism where the fraction of price changes evolves endogenously, as in state-dependent models, but it is as tractable as time-dependent models, so to be used for empirical and policy analysis. In their model, multiproduct firms can reset their prices in every period subject to an adjustment cost, as in standard menu costs models, but they choose how many, but not which, prices to adjust. This main assumption allows to solve the model without the need to keep track of the entire distribution of price changes. Moreover, they perform a Bayesian estimation of the aggregate shock parameters, as well as some of the price-setting parameters, on US data using a third-order approximation of the non-linear model. Despite a different mechanism, their model share similar implications as ours, because it replicates, as ours, many features of state-dependent models, as an endogenous fraction of price changes, the amplification of inflation response and a more favorable stabilization trade-off in high-inflation environment. Their model does not feature state-dependency in wage setting, however, as well as other elements that the literature has proved to be important for empirical analysis – as habit persistence or price and wage indexation –, and estimates a much smaller subset of parameters. Moreover, they use US data, so we see our works as complementary to theirs.

Reiter and Wende (2024) is another recent paper that proposes a yet different mechanism, based on a generalization of the Rotemberg pricing model. The mechanism is based on the assumption that marginal cost follows a sigmoid function, and it is then embedded in a calibrated DSGE model to show that it has similar aggregate implications as the menu cost models in Costain and Nakov (2019).

Our paper also relates to recent studies on optimal monetary policy in nonlinear calibrated state-dependent models. Karadi et al. (2024) find that central banks should respond to major cost-push shocks with a more aggressive anti-inflation policy, since the more favorable stabilization trade-off reduces the economic cost of controlling inflation. Additionally, they find that in the case of an aggregate productivity shock, which does not create any trade-off, the optimal policy emphasizes strict price stability. In a multisector economy with menu costs, Caratelli and Halperin (2025) find that optimal policy should, instead, allow inflation to move after sectoral productivity shocks, with inflation and output move in opposite direction. The optimal policy prescription in their model entails nominal wage targeting, i.e., nominal wages, rather than inflation, should be stabilized, despite wages being flexible.

Finally, our work relates to a large empirical research dealing with non-linear inflation dynamics and its implications for monetary policy. Some studies provide empirical evidence of non-linearity in the aggregate response of inflation to shocks, that are consistent with state-dependent price- and wage-setting (see, e.g., Alvarez et al., 2017; Ascari and Haber, 2022; Cavallo et al., 2024; de Veirman, 2023). Non-linearity in the Phillips curve could arise for different reasons than state-dependent pricing. Harding et al. (2022, 2023) show that the non-linear standard Calvo model with a Kimball aggregator gives rise to a non-linear Phillips Curve, and then study the implications for monetary policy under de- or accelerating inflation. Erceg et al. (2024) extend this framework by allowing for endogenous indexation of prices and wages, whereby the share of backward-looking price and wage setting by firms and households increases with the level and persistence of above-target inflation. Benigno and Eggertsson (2023) and Gitti (2025) provide evidence suggesting that the Phillips curve is strongly non-linear in the vacancy-to-unemployment ratio, as a measure of labor market tightness. Faber and Züllig (2025) present similar evidence for a panel of 18 euro area countries area, using unemployment as measure of labor market slack. However, Beaudry et al. (2024, 2025) argue that this evidence is fragile, and that non-linearities may only reflect shifts in short-run inflation expectations. This is in line with evidence for the US in Gorodnichenko and Coibion (2025), and for Europe in Acharya et al. (2023).

2 The model

In this section, we detail the microfoundations of the model in Subsection 2.1. After that, we present the non-linear solution in Subsection 2.2.

2.1 Microfoundations

Time t is discrete. We borrow the notation from Sims and Wu (2021) and develop a New Keynesian model with consumption habits, indexation to lagged inflation, and state-dependent sticky prices and wages following Gasteiger and Grimaud (2023). The state dependency allows for intensive *and* extensive margin adjustments in prices and wages.

Households. The lifetime utility of household $k \in [0,1]$ is given by

$$\mathbb{E}_t \sum_{j=0}^{\infty} \beta^j \left\{ \frac{1}{1-\sigma} \left(\frac{C_{t+j}(k)}{C^h_{t-1+j}} \right)^{1-\sigma} C^h_{t-1+j} - \frac{\psi}{1+\chi} L_{t+j}(k)^{1+\chi} \right\}$$

with relative risk aversion $\sigma > 1$, discount factor $0 < \beta < 1$, $\psi > 0$ is a scaling parameter for labor disutility, and, χ is the inverse Frisch elasticity. We incorporate multiplicative external consumption habits into the utility function via parameter $0 \leq h < 1$. This creates complementarities between individual agent consumption at time t and aggregate consumption at $t-1$. The utility function is increasing and concave in both individual and aggregate consumption. When the habit parameter $h = 0$, the utility function collapses to standard CRRA preferences. This formulation allows for the introduction of consumption smoothing in Section 4 while avoiding negative marginal utility, which could destabilize the model under nonlinear simulations in response to large shocks.[1]

Household k, faces the nominal budget constraint

$$P_t C_t(k) + B_t(k) \leq (1-\varepsilon_{w,t}) MRS_t L_t(k) + (1-\varepsilon_{d,t}) R_{t-1} B_{t-1}(k) + DIV_t + T_t,$$

where P_t represents the price level of goods, and B_t denotes a one-period bond that pays the short-term gross interest rate R_t. The term MRS_t corresponds to the nominal remuneration households earn by supplying labor to the union. DIV_t captures the dividends households receive as owners of intermediate goods-producing firms, while T_t represents lump-sum taxes net of subsidies, ensuring the government budget constraint is balanced.

Two exogenous AR(1) processes, $\varepsilon_{w,t}$ and $\varepsilon_{d,t}$, are introduced to generate variations in distortionary taxes or subsidies on wages and on bond income. These processes are intro-

[1] In Figure F.1, Appendix F, we demonstrate the robustness of this assumption by comparing it to the standard additive formulation $\frac{(C_{t+j}(k)-hC_{t-1+j})^{1-\sigma}}{1-\sigma}$ in the context of small shocks, at our quantitative model posteriors' mode, showing quantitative differences when using the same parameters set but little discrepancy in the propagation of the shocks.

duced for estimation purposes. They effectively represent a labor supply shock ($\varepsilon_{w,t}$) and a shock ($\varepsilon_{d,t}$) creating a wedge between the central bank's policy rate and the return on assets held by households, similar to Smets and Wouters's (2007) risk premium shock.

Aggregating over homogeneous households and dropping the k index, the first-order conditions for a representative agent in real terms are

$$\psi L_t^{\chi}(C_t C_{t-1}^{-h})^{\sigma} = (1-\varepsilon_{w,t}) mrs_t$$

$$1 = (1-\varepsilon_{d,t}) R_t \mathbb{E}_t \Lambda_{t,t+1} \pi_{t+1}^{-1}$$

$$\Lambda_{t,t+1} = \beta \left(\frac{C_{t+1} C_t^{-h}}{C_t C_{t-1}^{-h}} \right)^{-\sigma}$$

with $\pi_t = P_t / P_{t-1}$ the gross inflation rate, $mrs_t = MRS_t / P_t$ the real remuneration for labor supply and $\Lambda_{t,t+1}$ the the real stochastic discount factor. Clearly, multiplicative consumption habits affect both the labor supply and the inter-temporal consumption decision.

Labor market. The labor market consists of three layers. There is a continuum of labor unions index by $l \in [0,1]$. They purchase labor from households at MRS_t and repackage it for sale to a representative labor packer $W_t(l)$. The labor packer combines differentiated labor inputs into final labor, $L_{d,t}$, via a CES technology with elasticity of substitution $\epsilon_w > 1$. Therefore, the labor demand curve faced by each union l is

$$L_t(l) = \left(\frac{W_t(l)}{W_t} \right)^{-\epsilon_w} L_{d,t},$$

and, the aggregate wage index is

$$W_t^{1-\epsilon_w} = \int_0^1 W_t(l)^{1-\epsilon_w} dl.$$

Labor unions are wage setters. Following Gasteiger and Grimaud (2023), the problem for union l that updates optimally is to choose a wage that maximizes the discounted value of future real profits. Unions apply the household's stochastic discount factor to get the net present value of profits, and take the time-varying wage-setting frequency as given, i.e.,

$$\max_{W_t(l)} \mathbb{E}_t \sum_{j=0}^{\infty} \left(\prod_{k=0}^{j} \phi_{w,t+k} \right) \phi_{w,t}^{-1} \Lambda_{t,t+j}$$
$$\times \left\{ (W_t(l) \Pi_{t,t+j}^{\varrho_w})^{1-\epsilon_w} W_{t+j}^{\epsilon_w} P_{t+j}^{-1} L_{d,t+j} - mrs_{t+j} (W_t(l) \Pi_{t,t+j}^{\varrho_w})^{-\epsilon_w} W_{t+j}^{\epsilon_w} L_{d,t+j} \right\}$$

with

$$\Pi_{t,t+j} \equiv \begin{cases} \frac{P_{t+1}}{P_t} \times \frac{P_{t+2}}{P_{t+1}} \times \ldots \times \frac{P_{t+j}}{P_{t+j-1}} & \text{for } j = 1,2,\ldots \\ 1 & \text{for } j = 0. \end{cases}$$

$0 \leq \varrho_w < 1$ captures partial indexation of wages to past inflation. Assuming that the reset wage is the same across all labor unions, the index l can be dropped. The first-order condition defining optimal reset wage $W_t^{\#}$ can be written in real terms as

$$w_t^{\#} = \frac{\epsilon_w}{\epsilon_w - 1} \frac{F_{1,t}}{F_{2,t}},$$

where

$$F_{1,t} = mrs_t w_t^{\epsilon_w} (P_t / \Pi_{t,t+j}^{\varrho_w})^{\epsilon_w} L_{d,t} + \mathbb{E}_t \phi_{w,t+1} \Lambda_{t,t+1} F_{1,t+1}$$
$$F_{2,t} = w_t^{\epsilon_w} (P_t / \Pi_{t,t+j}^{\varrho_w})^{\epsilon_w - 1} L_{d,t} + \mathbb{E}_t \phi_{w,t+1} \Lambda_{t,t+1} F_{2,t+1}$$

Defining $f_{1,t} = F_{1,t} / P_t^{\epsilon_w}$ and $f_{2,t} = F_{2,t} / P_t^{\epsilon_w - 1}$ we get

$$w_t^{\#} = \frac{\epsilon_w}{\epsilon_w - 1} \frac{f_{1,t}}{f_{2,t}},$$

where

$$f_{1,t} = mrs_t w_t^{\epsilon_w} L_{d,t} + \mathbb{E}_t \phi_{w,t+1} \Lambda_{t,t+1} \left(\frac{\pi_{t+1}}{\pi_t^{\varrho_w}} \right)^{\epsilon_w} f_{1,t+1}$$
$$f_{2,t} = w_t^{\epsilon_w} L_{d,t} + \mathbb{E}_t \phi_{w,t+1} \Lambda_{t,t+1} \left(\frac{\pi_{t+1}}{\pi_t^{\varrho_w}} \right)^{\epsilon_w - 1} f_{2,t+1}.$$

Wage resetting agency. Whether a union updates the wage is modeled as a discrete choice (Matějka and McKay, 2015). The benefit of optimally updating is quantified based on the expected present value of the union's dividends when setting $w_t^{\#} \equiv W_t^{\#} / P_t$ (the optimal real wage), which we denote $V_{w,t}^{\#}$. When the expected present value of the union's dividends implied by $w_t^{\#}$, net of the cost, increases with respect to the benefit of maintaining the price, managers have a higher incentive to reset the price.

Nonetheless, maintaining the wage has different implications for each individual union. Each union l has a different old wage and thus faces a different opportunity cost of changing the wage $V_{w,l,t}^{f}$. This heterogeneity among unions increases the complexity in quantifying the benefit of maintaining the price at the cost of model tractability. We bypass this issue by introducing a wage resetting agency. The wage resetting agency takes the resetting decision for the unions. It does so by quantifying the benefit of maintaining the wage as the expected present value of the union's surplus when choosing the average relative old wage level in the economy $w_t^{f} \equiv W_t^{f} / P_t \equiv W_{t-1} / P_t \equiv W_{t-1} / P_t \times P_{t-1} / P_{t-1} \equiv w_{t-1} / \pi_t$ at no cost. We denote this benefit $V_{w,l,t}^{f} = V_{w,t}^{f}\ \forall l$, which we interpret as the average benefit of holding the wage.

The share of unions not updating wages optimally follows the multinomial logit model

$$\phi_{w,t} = \frac{\exp\left(\gamma_w V_{w,t}^f\right)}{\exp\left(\gamma_w V_{w,t}^f\right) + \exp\left(\gamma_w \left(V_{w,t}^{\#} - \tau_w\right)\right)}, \tag{1}$$

where $\phi_{w,t} \in [0,1]$ and $(1-\phi_{w,t})$ denotes the share of optimally updated wages, $\tau_w > 0$ is the wage updating cost, and $\gamma_w > 0$ is the elasticity of wage resetting frequency to variation in present values –also called the intensity of choice. When $\gamma_w \to 0$, the model collapses to the standard Calvo (1983) wage-setting model. The present value of the wage decision can be written recursively as

$$V_{w,t}^x = \left(w_t^{x^{1-\epsilon_w}} f_{2,t} - w_t^{x^{-\epsilon_p}} f_{1,t} \right) \tag{2}$$

for $x \in \{\#, f\}$. The derivations can be found in Appendix B.

Importantly, (1) introduces a nonlinearity central to the mechanism proposed in this paper. In steady state, the model nests pure time-dependent wage setting. Outside steady state, the wage resetting agency cost-benefit analysis gives rise to state-dependent wage setting: more wages are reset optimally when the benefits of resetting increase, and fewer when they decrease. Therefore, the $\phi_{w,t}$ decreases/increases when the difference between the present values of re-optimizing and not re-optimizing the wage increases/decreases. As discussed below, the asymmetry in (2) strengthens incentives to increase wages when demand is high or shocks are inflationary, accelerating wage inflation.

Production. Production is divided into several layers. A representative wholesale firm hires labor from the labor packer and produces output. The latter is sold to a continuum of retail firms at price $P_{w,t}$. Each retail firms $i \in [0,1]$ repackages wholesale output, and sells it to a competitive final goods firm at $P_t(f)$.

A final goods firm transforms retail output into a final output good according to $Y_t = \left[\int_0^1 Y_t(f)^{\frac{\epsilon_p - 1}{\epsilon_p}} df\right]^{\frac{\epsilon_p}{\epsilon_p - 1}}$. Profit maximization by the final goods firm gives a demand for each retail output as $Y_t(f) = \left(\frac{P_t(f)}{P_t}\right)^{-\epsilon_p} Y_t$, and, the aggregate price index as $P_t^{1-\epsilon_p} = \int_0^1 P_t(f)^{1-\epsilon_p} df$.

Retailers are price-setters. Following Gasteiger and Grimaud (2023), the retailers discount future real dividends with the stochastic discount factor of the household, as well as the time-varying price-setting frequency. The price-setting problem is therefore:

$$\max_{P_t(f)} \mathbb{E}_t \sum_{j=0}^{\infty} \left(\prod_{k=0}^{j} \phi_{p,t+k} \right) \phi_{p,t}^{-1} \Lambda_{t,t+j} \times$$
$$\times \left\{ P_t(f)^{1-\epsilon_p} (P_{t+j}/\Pi_{t,t+j}^{\varrho_p})^{\epsilon_p - 1} Y_{t+j} - P_{w,t+j} P_t(f)^{-\epsilon_p} (P_{t+j}/\Pi_{t,t+j}^{\varrho_p})^{-\epsilon_p} Y_{t+j} \right\},$$

where $0 \leq \varrho_p < 1$ is a parameter governing indexation to past inflation. We define the optimal reset price as $P_t^{\#}$, it does not depend on the index f. The first-order condition is recursively given by

$$P_t^{\#} = \frac{\epsilon_p}{\epsilon_p - 1} \frac{X_{1,t}}{X_{2,t}}$$

$$X_{1,t} = p_{w,t}(P_t / \Pi_{t,t}^{\varrho_p})^{\epsilon_p} Y_t + \mathbb{E}_t \phi_{p,t+1} \Lambda_{t,t+1} X_{1,t+1}$$

$$X_{2,t} = (P_t / \Pi_{t,t}^{\varrho_p})^{\epsilon_p - 1} Y_t + \mathbb{E}_t \phi_{p,t+1} \Lambda_{t,t+1} X_{2,t+1}$$

With $p_{w,t} = P_{w,t}/P_t$ interpreted as real marginal costs. We define $x_{1,t} = X_{1,t}/P_t^{\epsilon_p}$ and $x_{2,t} = X_{2,t}/P_t^{\epsilon_p - 1}$ so as to have

$$x_{1,t} = p_{w,t} Y_t + \mathbb{E}_t \phi_{p,t+1} \Lambda_{t,t+1} \left(\frac{\pi_{t+1}}{\pi_t^{\varrho_p}} \right)^{\epsilon_p} x_{1,t+1}$$

$$x_{2,t} = Y_t + \mathbb{E}_t \phi_{p,t+1} \Lambda_{t,t+1} \left(\frac{\pi_{t+1}}{\pi_t^{\varrho_p}} \right)^{\epsilon_p - 1} x_{2,t+1}$$

$$p_t^{\#} = \frac{\epsilon_p}{\epsilon_p - 1} \frac{x_{1,t}}{x_{2,t}}$$

with $p_t^{\#} = P_t^{\#}/P_t$. The wholesale firm produces output following

$$Y_{W,t} = L_{d,t}$$

Such that the optimality condition in real terms is given by

$$(1 - \varepsilon_{p,t}) w_t = p_{w,t},$$

in which $\varepsilon_{p,t}$ represents an exogenous tax or subsidy on marginal costs, introduced to generate supply-side inflationary shocks. Unlike labor supply shocks, these shocks move real wage and inflation in opposite directions.

Price resetting agency. The benefit of optimally updating the price is quantified based on the expected present value of the firm's profits when setting $p_t^{\#} \equiv P_t^{\#}/P_t \equiv \Pi_t^{\#}$ (the optimal relative price is equal to the optimal inflation rate), which we denote $V_{p,t}^{\#}$. When the expected present value of the firm's profits implied by $p_t^{\#}$ net of the cost increases with respect to the expected benefit of maintaining the old price, managers will reset the price more often.

Similar to the wage-setting model above, maintaining the old price has different implications for each individual firm. Each firm i has a different old price and thus faces a different opportunity cost of changing the price $V_{p,i,t}^{f}$. Again, we introduce a price resetting agency. The price resetting agency takes the resetting decision for the firms. It does so by quantifying the benefit of maintaining the price as the expected present value of the firm's profits when choosing the average relative old price level in the economy $p_t^f \equiv P_t^f/P_t \equiv P_{t-1}/P_t \equiv 1/\pi_t$ at no cost. We denote this benefit $V^f_{p,i,t} = V^f_{p,t}\ \forall i$, which we interpret as the average benefit of maintaining the price.

Thus, the share of firms not re-optimizing their old prices is given by

$$\phi_{p,t} = \frac{\exp\left(\gamma_p V^f_{p,t}\right)}{\exp\left(\gamma_p V^f_{p,t}\right) + \exp\left(\gamma_p \left(V^\#_{p,t} - \tau_p\right)\right)}, \tag{3}$$

where $\phi_{p,t} \in [0,1]$ and $(1-\phi_{p,t})$ denotes the share of updated prices, $\tau_p > 0$ is the price updating cost, and, $\gamma_p > 0$ is the elasticity of price resetting frequency to variation in present values –also called the intensity of choice. When $\gamma_p \to 0$, the model collapses the Calvo (1983) price-setting model. As long as $\gamma_p < \infty$ prices are rigid. The present value of expected profits implied by the pricing decision $x \in \{\#, f\}$ is obtained by evaluating the firm's objective function at relative price p^x_t. Recursively, this is

$$V^x_{p,t} = \left(p^{x^{1-\epsilon_p}}_t x_{2,t} - p^{x^{-\epsilon_p}}_t x_{1,t}\right). \tag{4}$$

Similar to (1), firms' price setting based on (3) is state-dependent and introduces a second non-linearity as another key element of the mechanism proposed in this paper. As discussed in Subsection 3.1 below (and in great detail in Gasteiger and Grimaud, 2023), the asymmetry in (4) strengthens incentives to increase prices when demand is high or shocks are inflationary, accelerating price inflation in combination with (3).

Monetary Policy. The gross nominal rate R_t is set according to a linear Taylor rule

$$R_t = \rho R_{t-1} + (1-\rho)\left(\overline{R} + \theta_\pi\left(\pi_t - \overline{\pi}\right) + \theta_y\left(\frac{Y_t}{\overline{Y}} - 1\right)\right) + \varepsilon_{r,t}$$

with θ_π the reaction to inflation deviation, θ_y the reaction to ouput gap, ρ the smoothing parameter, and $\varepsilon_{r,t}$ an AR(1) monetary policy shock.

Aggregation. Using the properties of Gasteiger and Grimaud (2023) derived from the Calvo (1983) model, we obtain that the aggregate inflation rate and aggregate real wages laws of motion

$$1 = \left(1-\phi_{p,t}\right)\left(\pi^\#_t\right)^{1-\epsilon_p} + \phi_{p,t}\left(\frac{\pi_t}{\pi^{\varrho_p}_{t-1}}\right)^{\epsilon_p - 1}$$

$$w^{1-\epsilon_w}_t = \left(1-\phi_{w,t}\right)\left(w^\#_t\right)^{1-\epsilon_w} + \phi_{w,t}\left(\frac{\pi_t}{\pi^{\varrho_w}_{t-1}}\right)^{\epsilon_w - 1} w^{1-\epsilon_w}_{t-1}$$

Aggregate production function across the continuum of retailers is

$$Y_{W,t} = Y_t v^p_t$$

with $v_t^p = \int_0^1 \left(\frac{P_t(f)}{P_t}\right)^{-\epsilon_p} df$ being a measure of price dispersion, that we can write recursively, i.e.,

$$v_t^p = (1-\phi_{p,t})\left(\pi_t^{\#}\right)^{-\epsilon_p} + \phi_{p,t}\left(\frac{\pi_t}{\pi_{t-1}^{\varrho_p}}\right)^{\epsilon_p} v_{t-1}^p.$$

For labor market clearing, we integrate the demand for union labors across unions and obtain

$$L_t = L_{d,t} v_t^w$$

with $v_t^w = \int_0^1 \left(\frac{w_t(h)}{P_t}\right)^{-\epsilon_p} dh$ being a measure of wage dispersion, which can also be written recursively, i.e.,

$$v_t^w = (1-\phi_{w,t})\left(\frac{w_t^{\#}}{w_t}\right)^{-\epsilon_w} + \phi_{w,t}\left(\frac{\pi_t}{\pi_{t-1}^{\varrho_w}}\right)^{\epsilon_w}\left(\frac{w_t}{w_{t-1}}\right)^{\epsilon_w} v_{t-1}^w.$$

Bonds are in zero net supply. Therefore the aggregate resource constraint is

$$Y_t = C_t.$$

Exogenous process. We have 4 exogenous variables, two supply shocks – a cost-push shock ε_t^p and a labor supply shock ε_t^w – and two demand shocks – a risk premium shock ε_t^d and a monetary policy shock ε_t^r. We assume that they follow a stationary AR(1) processes.

$$\varepsilon_t^z = \rho_z \varepsilon_{t-1}^z + \eta_{z,t},$$

with $\eta_{z,t} \sim$ i.i.d. $\mathcal{N}(0, \sigma_z^2)$, and $0 \le \rho_z < 1$ for $z = \{d, p, w, r\}$.

2.2 The extended path solution method.

This paper explores the non-linearities of the Phillips curve and the interactions between the intensive and extensive margins of inflation. A first-order linearization is inadequate for approximating the model, as it fails to capture the state-dependent dynamics driven by asymmetric profit functions. The state-dependent adjustment frequencies for prices and wages generate essential nonlinearities and asymmetries in inflation and wage responses to shocks, requiring a fully nonlinear estimation approach. To accurately capture these non-linearities, we solve the model using the extended path method developed by Fair and Taylor (1983), following the recent implementation by Adjemian and Juillard (2024); Sahuc et al. (2025). This method provides a nonlinear solution under rational expectations, responding to MIT-type shocks without aggregate uncertainty.[2] Specifically, agents are assumed to be surprised by contemporaneous shocks, but consistently expect future shocks to be zero, consistent with

[2]Explicit integration over future uncertainty would offer limited additional accuracy given the CRRA specification of the utility function and does not justify the significant computational cost involved.

rational expectations. The numeric solution can be expressed as follows:

$$y_t = \mathbb{E}_{t,t+S}\left\{g_\Theta\left(y_{t-1}, \bar{y}, \eta_t\right)\right\}, \quad (5)$$

where y_t denotes the vector of endogenous variables, $g_\Theta(\cdot)$ is the nonlinear transition function implied by the structural equations, Θ represents the set of structural parameters, and shocks are normally distributed as $\eta_t \sim N(0, \Sigma_\eta)$. The expectation operator $\mathbb{E}_{t,t+S}$ implies a sequence-space approximation of expected fluctuations over a horizon of S periods, beyond which the economy has fully returned to steady state $\bar{y}$. We choose a sequence-space horizon of 10 years ($S = 40$ quarters), as extending this horizon further does not significantly alter the likelihood. Importantly, this numerical solution explicitly accounts for endogenous variations in the Calvo adjustment probabilities, which are central to our model.

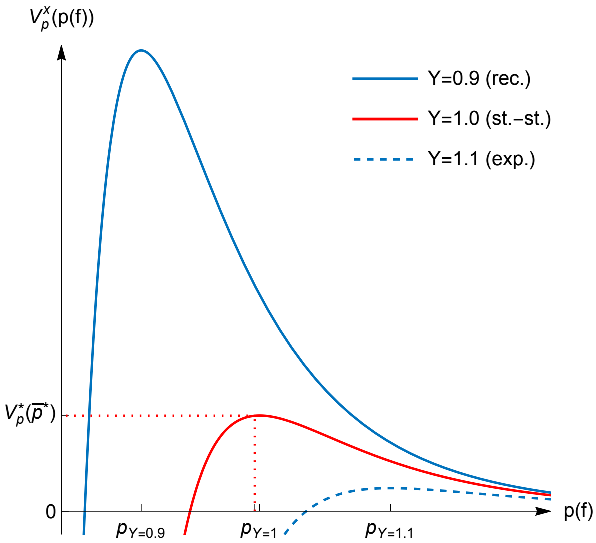
3 Monetary policy under non linear Phillips curves

We begin by calibrating the model to match a small-scale setup[3] to build intuition about the role of endogenous versus exogenous price and wage setting frequencies. Section 3.1 contrasts the shape of both the price and wage New Keynesian Phillips curves when the economy is hit by demand and supply shocks. Section 3.2 compares state-dependent IRFs in response to different shocks, depending on the value of the underlying inflation processes. Finally, Section 3.3 shows how the sign and the size of the shocks matter for their propagation.

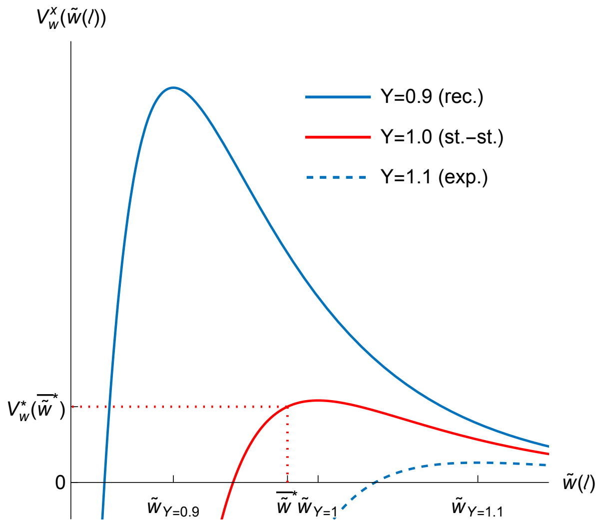
3.1 Implied Phillips curves and intuition

This subsection provides the intuition behind wage and price setting in the model, emphasizing the differences between fixed and endogenous adjustment frequencies. We extend the analysis in Gasteiger and Grimaud (2023), who focused exclusively on price-setting and demand shocks, to include both price and wage adjustments and supply shocks. We show that endogenous price- and wage-setting frequencies give rise to non-linear New Keynesian Phillips curves that are steeper for positive demand shocks and flatter for negative demand shocks for both price and wage. This result arises because of the asymmetry in the price

[3] We assume that the discount factor is set to $\beta = 0.995$, and the curvature of consumption utility is set to $\sigma = 2$. To neutralize the effects of price and wage dispersion on labor supply and marginal cost, we impose $\chi = 0$. The Taylor rule follows standard values for the euro area, with coefficients $\{\theta_\pi, \theta_y, \rho\} = \{2, 0.125, 0.8\}$. The gross steady-state inflation rate is set to $\overline{\pi} = 1.005$. The elasticities of demand for individual goods and labor are set to $\varepsilon_p = \varepsilon_w = 9$. The steady-state shares of firms and unions not optimally resetting prices and wages are calibrated to $\{\overline{\phi}_p, \overline{\phi}_w\} = \{0.75, 0.85\}$, consistent with standard values used in the literature on Calvo pricing. We follow Gasteiger and Grimaud (2023) and set the state dependency parameters to $\gamma_\pi = \gamma_w = 10$. The autoregressive coefficients of the exogenous shocks are set to $\rho_d = \rho_p = \rho_w = 0.8$, while monetary policy shocks are assumed to be purely i.i.d. Finally, to simplify the analysis and focus on the role of state dependency, we shut down most sources of endogenous persistence by setting $h = \varrho_\pi = \varrho_w = 0$.



(a) Firms



(b) Unions

Figure 1: **Asymmetry in wage and price setting decisions.** The lines depict the present values of firms (Panel (a)) and unions (Panel (b)), as a function of output and their relative price and wage (atomistic firm and union in partial equilibrium)

and wage setting decision. For a given updating cost, the benefits of increasing prices and wages, following an increase in demand or in prices and wages, are larger than the benefits of decreasing them, when demand or prices and wages decrease.

Asymmetry in price and wages setting decisions. Panel 1a depicts firm f's present value in steady state as a function of its relative price $p(f) = P(f)/P$. The depicted present value measures the firm f's benefit in partial equilibrium, i.e., holding all other variables at their steady state (red line). The blue solid line and blue dashed line depict the present value for a lower or higher output level.

Two observations stand out. First, the relative price associated with the present value's peak is higher, if the output level is higher. The latter is because firm f's present value depends on current and future expected pro-cyclical marginal costs. Thus, higher output creates an incentive to increase the price and lower output creates an incentive to cut the price.

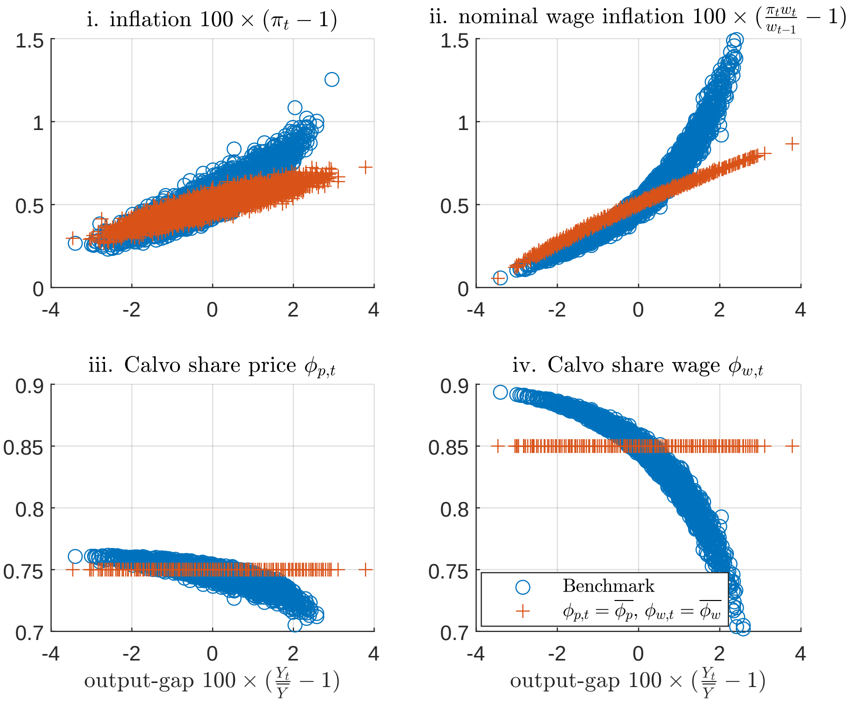
Second, the present value exhibits asymmetry, which is due to the nonlinear profit functions given the Dixit and Stiglitz (1977) monopolistic competition setting. As discussed in greater detail in Gasteiger and Grimaud (2023), because of this asymmetry in the present value, low relative prices imply relatively larger reductions in the present value. The opportunity cost is mainly in terms of profit per unit. In contrast, high relative prices imply relatively smaller reductions in the present value. The opportunity cost is mainly in terms of foregone quantity. Hence, the asymmetry of the present value undermines the incentive to cut the price when demand falls and strengthens the incentive to increase the price when demand increases.

Finally, recall that Panel 1a depicts firm f's present value as a function of its relative price. Thus, all else equal, any increase in the aggregate price level, say due to an inflationary supply shock, implies a decrease in firm f's relative price. Inspection of the depicted present value clarifies that this again creates a strong incentive to increase the price because of the aforementioned asymmetry. However, again the opposite is less true in case of a disinflationary supply shock.

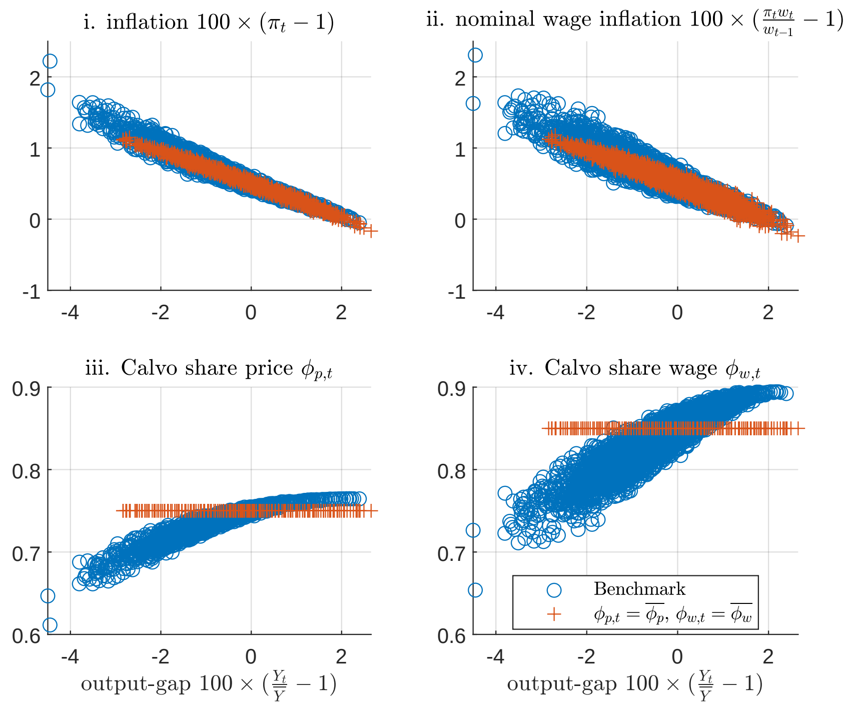
In analogy to Panel 1a above, Panel 1b depicts union l's present value in steady state as a function of its relative wage $\tilde{w}(l) = W(l)/W$. The case of union l parallels the previous case of firm f. First, as in the case of firm f, the relative wage associated with the peak of the present value is higher for union l, if the output level is higher. In the case of union l, this is because its present value depends on current and future expected pro-cyclical marginal rates of substitution. Second, also union l's present value is asymmetric. Hence, higher demand (or an inflationary aggregate shock) creates an incentive to increase the wage, while lower demand (or a disinflationary aggregate shock) creates an incentive to reduce the wage. However, given the aforementioned asymmetry in the present value, the incentives to reduce wages are low, whereas the incentives to increase wages are strong.

Non-linear Philips Curves. Figure 2 visualizes the implications of the asymmetry in price and wage decisions for the response of the model after a demand shock and a supply shock. Each panel displays as dots the simulation of 10,000 periods conditional to stochastic monetary policy and labor supply shocks in our benchmark model (blue circle) and the standard Calvo model (red plus).[4] Figure 2a reports results for monetary policy shocks, one of the model's demand-side shocks. Demand shocks move both output and inflation in the same direction. The blue circles reveal the non-linear dynamics of the model under state-dependent price and wage-setting. The non-linear behavior of the Phillips curve in our model is driven by the interaction of two distinct channels: (i) on the intensive margin, higher demand increases the optimal resetting price for firms, directly raising inflation (as in a Calvo model), (ii) on the extensive margin, higher demand boosts the present discounted value of resetting prices, further amplifying inflation by increasing the frequency of price adjustments. The same mechanisms apply to labor unions' wage-setting decisions. Note that, in general equilibrium, the non-linearity of wage and price setting decisions reinforce each other. Higher price level reduces real wages, increasing the marginal rate of substitution and therefore the incentive for unions to reset nominal wages upward. This adjustment pushes up marginal costs, reinforcing inflationary pressures through a feedback loop. Consequently, both price *and* wage Phillips curves exhibit convexity, linking inflation dynamics across the goods and labor markets. In other words, as demand shocks, monetary policy shocks in Figure 2a trace out, therefore, non-linear aggregate supply curves.

[4] In the absence of habit and indexation, the degree of endogenous persistence is relatively modest, allowing us to clearly decompose the conditional Phillips curves. These conditional Phillips curves can be interpreted as proxies for the underlying aggregate demand and supply curves (see Bergholt et al., 2024).



(a) Monetary policy shocks



(b) Labor supply shocks

Figure 2: **Phillips curves are curves.** The dots show the results of stochastic simulated runs of the output gap and of (i) price inflation, (ii) wage inflation, (iii) the share of not-adjusting firms; (iv) the share of not-adjusting unions, respectively, in the case of monetary policy shocks (Panel (a)) and labor supply shocks (Panel (b)).

Notes: The distribution of Gaussian shocks follows the estimated volatility of the monetary policy (top panels), and labor supply shock (bottom-panels), respectively. For the sake of brevity, we refer to the share of non-reoptimized wages or prices displayed in the chart as the Calvo shares.

Without state-dependency (i.e., setting $\gamma_p, \gamma_w \to 0$), the model reverts to the standard NK model, which produces a quasi-linear relationship between output and price or wage inflation in response to demand-side shocks, as shown by the red pluses in Figure 2a.

Figure 2b presents similar simulations conditional on only labor supply shocks, as an example of supply disturbances. The shocks move price and wage inflation in the same direction and output in opposite directions, generating negative sloped (wage and price) Phillips curves. Labor supply shocks in Figure 2a trace out actually an aggregate demand relationship.

By reducing labor supply, the shocks drive up real wages, increasing marginal costs and, ultimately, prices. In the standard NK model (red pluses), these shocks generate a quasi-linear relationship between marginal costs, inflation, and output. In contrast, in the state-dependent model, the extensive margin creates non-linear effects due to the asymmetry analyzed above, which is evident when comparing the effects of inflationary and deflationary supply shocks. Inflationary supply shocks, which raise marginal costs, lead to more frequent price and wage resets (see Panel (iii) and (iv) in Figure 2b), thus generating strong upward pressures on prices and wages. On the contrary, deflationary shocks have weaker effects, as adjustment frequencies are less responsive to falling prices. As a result, the blue circles in Panel (i) and (ii) in Figure 2b stretch (and fan) out the red pluses when inflation is on the upside, while they lie over the red pluses when inflation is on the downside. The extensive margin amplifies the inflationary pressure of adverse supply shocks, but this effect is not symmetric: deflationary pressure of benign supply shocks is not amplified with respect to the standard Calvo model.

In sum, Figure 2 visualizes the strong correlation between inflation and the frequency of price and wage resets that our model generates. During periods of high inflation, price and wage resets increase, reflecting the state-dependent nature of the adjustment process. In the fixed adjustment probability model of Calvo (1983), these channels are deactivated, leading to constant adjustment frequencies, and quasi-linear price and wage Phillips curves under both demand and supply side shocks. In such a setting, inflationary responses to shocks are proportional to marginal cost fluctuations, and the rich interplay between the resetting frequency and inflation vanishes. This underscores the key role of state dependency in shaping nonlinear inflation-output trade-offs observed in the price and wage Phillips curves.

Effect of Trend Inflation. Appendix C shows that higher steady-state inflation raises the frequency of wage and price adjustment, as both firms (and unions) choose to adjust prices (and wages) more frequently, thereby leading to a more flexible economy. Moreover, the Appendix illustrates that this feature of our model is both quantitatively and qualitatively consistent with results as in, e.g., L'Huillier and Schoenle (2024) for the US. Finally, Figure C.2 displays the effect of trend inflation on the IRFs to monetary and cost-push shocks, showing that the changes in first moments affects second moments, amplifying the effects of monetary policy shocks on inflation and the ones of cost-push shocks on output.

3.2 On the state-dependent effects of shocks

One of the main contributions of this paper is to show that the interaction between state-dependent price and wage setting, along with their implied non-linear Phillips curves, leads to state dependency in the effects of exogenous shocks. As in the previous subsection 3.1, throughout the paper we will focus on the difference between monetary policy shocks, as a demand shock, and cost-push or labor supply shocks, as a supply shock. This allows us to investigate the effects of policy shocks moving prices and quantities in the same direction, as well as the trade-off generated by shocks moving them in the opposite way.

Unlike the quasi-linear standard NK Calvo model, where responses are uniform regardless of initial conditions, our model implies that the responses to shocks are state dependent, meaning that they differ depending on the condition of the economy, that is, are contingent to the particular shocks the economy has been subject to.

Figure D.1 in Appendix D visualizes the state-dependency of IRFs to a monetary policy shock and a cost-push shock, after the economy has been subject to different inflationary shocks (see Appendix D for details). When starting from higher initial inflation levels, the economy exhibits greater flexibility in prices and wages (due to lower share of firms and unions not optimally updating the price and wage), leading to steeper Phillips curves. This increased steepness means that a given monetary policy shock will result in a more pronounced change in inflation and a smaller alteration in output. Additionally, high inflation environments lead to significantly steeper New Keynesian Phillips Curves (NKPCs) for both wages and prices, causing real wages to adjust more strongly and immediately to demand shocks, due to increased economic flexibility. However, this heightened flexibility also ensures that these real wage deviations are less persistent.

The mechanism behind cost-push shocks resembles that of monetary policy shocks, where higher inflation increases economic flexibility, amplifying the immediate impact of supply shocks on inflation and output. Initially, an adverse cost-push shocks trigger a divergence between price and wage inflation: firms raise prices, reducing demand and both nominal and real wages. This short-run decline in wage inflation weakens unions' incentives to adjust wages, leading to fewer wage resets. Over time, however, as inflation remains elevated, wage-setting becomes more responsive, with wages adjusting upward to match rising prices through a price-to-wage feedback loop. This interaction between different margins of wage and price flexibility makes the economic adjustment to negative supply shocks – via lower real wages and output – highly persistent, regardless of the initial inflation level.[5]

To underscore those dynamics, Figure 3 shows the output-inflation stabilization trade-off

[5]See again Appendix D for details. Figure F.2 in Appendix F present the IRFs to these two shocks originating from the steady state, with and without time-varying updating frequencies.

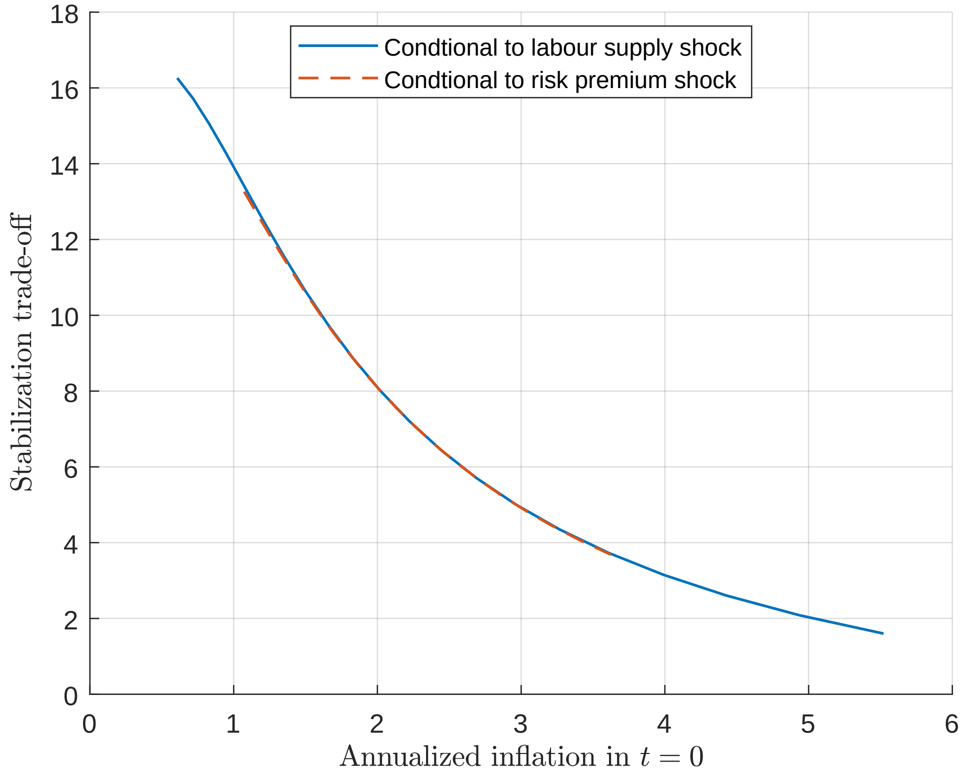


Figure 3: **The output-inflation stabilization trade-off for monetary policy depends on the level of inflation.** The lines decreases in the level of initial inflation, meaning that the higher the level of inflation, the more monetary policy affects inflation relative to output.
Notes: The stabilization trade-off is measured throughout this paper as the average ratio of cumulative output gap to inflation deviations over 20 quarters in response to +0.25% monetary policy shock.

that monetary policy is facing, computed from simulations conditioned on different starting inflation levels (the solid blue line is the case in which we condition on labor supply shocks only, the red dashed line is with risk premium shocks only). The stabilization trade-off is defined throughout this paper as the average ratio of cumulative output gap deviations to cumulative inflation deviations over 20 quarters in response to a 0.25% monetary policy shock. The results are striking: at an annualized inflation rate of 0.5%, the stabilization trade-off is 7 times larger than at 5%. This indicates that monetary policy is more effective at controlling inflation when starting from high inflation levels, as the steeper Phillips curves amplify the response of inflation to monetary policy shocks. Notably, this effect holds regardless of whether underlying inflation is driven by labor supply or risk premium shocks.

3.3 Size and sign dependency

Given the model's inherent non-linearity, shock propagation is both sign- and size-dependent. This can have important implications for the question of whether central banks should look through supply shocks. Figure 4 displays normalized IRFs to positive and negative cost-push

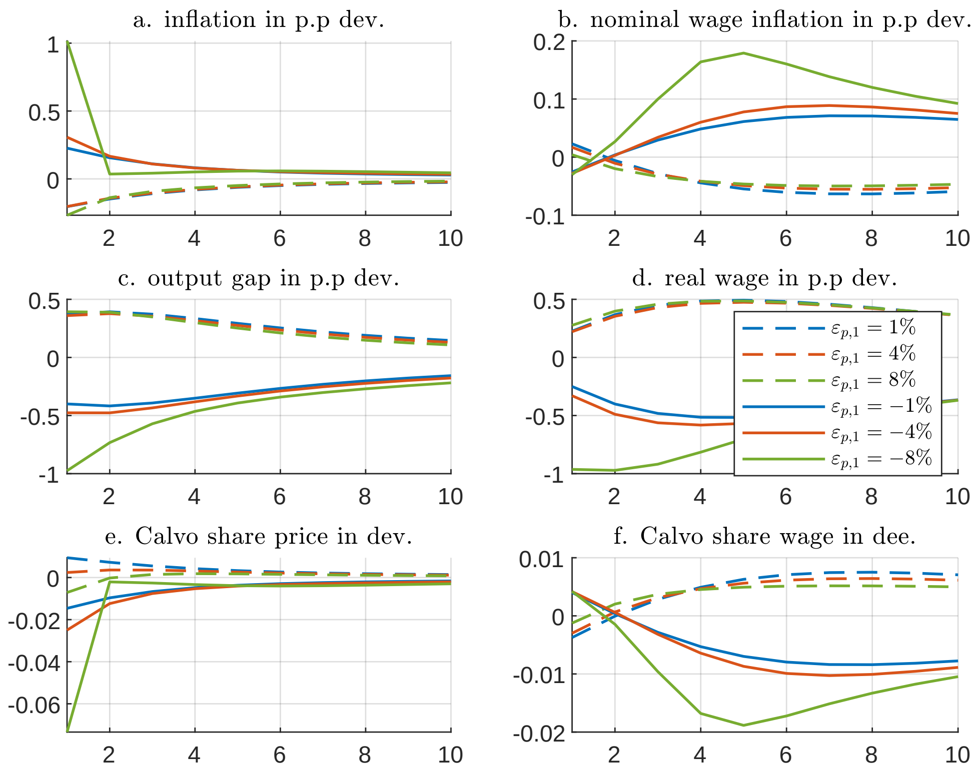


Figure 4: **Size and sign dependency in the response to a cost-push shock.** The different lines correspond to different sizes of (positive and negative) cost push shocks
Notes: The responses to the shocks are normalized to a 1% cost-push shock. We refer to the share of non-reoptimized wages or prices displayed in the chart as the Calvo shares.

shocks, highlighting that larger inflationary shocks amplify the intensive margin response. This implies that price inflation reacts more strongly to large shocks but with lower persistence, as price adjustments accelerate in response to stronger inflationary pressures. Regarding wage inflation, we observe that a larger initial real wage loss leads to greater wage flexibility, which in turn amplifies the persistence of nominal wage inflation.

The underlying mechanism aligns with the state-dependent pricing intuition discussed earlier, where higher inflation triggers more frequent price and wage updates. In contrast to labor supply shocks, cost-push shocks exhibit a different propagation pattern, as the response of $\phi_{w,t}$ remains largely size-invariant on impact. This distinction arises because cost-push shocks directly alter firms' marginal costs, lowering pricing frictions, whereas labor supply shocks primarily shift wage-setting incentives inducing non-linear responses in wage adjustment frequencies on impact.

Furthermore, the asymmetry in firms' profit functions reinforces sign dependency. While inflationary shocks increase price-resetting frequency, disinflationary shocks exhibit weaker size effects, as firms are less inclined to reduce their price adjustment frequency significantly. This is evident in the muted response of price and wage resetting frequencies following deflationary shocks. As a result, large inflationary shocks make the economy more flexible by increasing price adjustment rates, while disinflationary shocks fail to generate a symmetric reduction in price-setting activity which implies linear scaling.

4 A tale of two quantitative models

Building on the intuition of the small-scale model in Section 3, this section examines how time-varying updating frequencies affect the estimation of quantitative NK models, particularly focusing on the recent inflation surge period. To make the model more operational, we extend the framework to allow for consumption habits, as well as price and wage indexation to past inflation. We then estimate two specifications of this non-linear model. In the first specification, referred to as the benchmark model or the model with time-varying updating frequencies, the parameters γ_p and γ_w are estimated. In the second specification, called the model with fixed updating frequencies, we effectively remove state dependency by setting $\gamma_p \to 0$ and $\gamma_w \to 0$. Both estimations rely on the same dataset and follow an identical estimation procedure. Additionally, the priors are consistently specified across both versions.

4.1 Estimation strategy

Filtering method. The state-dependent adjustment frequencies for prices and wages require a fully nonlinear estimation approach. To bring this nonlinear model to the data, we use the inversion filter developed by Cuba-Borda et al. (2019); Guerrieri and Iacoviello (2017) and adapted to the extended path context by Sahuc et al. (2025). Given the observed sample $\{\mathcal{Y}_t\}_{t=1}^T$, the inversion filter recursively recovers structural shocks $\{\eta_t\}_{t=1}^T$ from the model observation equations and nonlinear solution paths derived from equation (5). The observation equation is given by:

$$\mathcal{Y}_t = h_\Theta(y_t), \tag{6}$$

where $h_\Theta(y_t)$ is is the vector of measurement equations in (5) and Θ is the set of structural parameters. For a candidate vector of estimated parameters $\theta \subset \Theta$, the likelihood function of the model $L(\theta, \mathcal{Y}_{1:T})$ is evaluated from the filtered sequence of shocks $\{\eta_t\}_{t=1}^T$. Following standard Bayesian practice in the DSGE literature (An and Schorfheide, 2007), we combine likelihood with prior distributions. Parametric uncertainty is assessed numerically via Markov Chain Monte Carlo (MCMC) sampling using the Metropolis-Hastings algorithm. Specifically, we generate 400,000 posterior draws across eight parallel chains, each running 50,000 iterations after a burn-in period of 50,000 draws. The scale parameter of the proposal distribution is adjusted to achieve an acceptance rate close to 33%.

Observation equations and Data. Our dataset consists of four quarterly macroeconomic time series spanning the period from 1999Q1 to 2024Q4. The mapping between these observed variables and the model-implied quantities is summarized in the system of observation equations below, corresponding to an expanded version of (6):

$$\begin{bmatrix} \text{Real output growth per cap., lin. detrended} \\ \text{Inflation rate quarterly (HICP)} \\ \text{Quater. policy rate (Krippner SR) adj. lvl} \\ \text{Real hourly wage growth , lin. detrended} \end{bmatrix} = \begin{bmatrix} 100 \times (\frac{Y_t}{Y_{t-1}} - 1) + \mathbb{1}_{t=2020Q2}\alpha_{y,1} + \mathbb{1}_{t=2020Q3}\alpha_{y,2} \\ 100 \times (\pi_t - 1) \\ 100 \times (R_t - 1) + \overline{r} \\ 100 \times (\frac{w_t}{w_{t-1}} - 1) + \mathbb{1}_{t=2020Q2}\alpha_{w,1} + \mathbb{1}_{t=2020Q3}\alpha_{w,2} \end{bmatrix}.$$

We next discuss the data transformation. All, data is based on EA changing composition. We first start with GDP transformation. We de-trend the real output growth series with linear trend to account for the fact that our model abstracts from exogenous long-run GDP growth. For prices and wages, we use HICP and real hourly wages – detrended nominal compensation of employee divided by total employment deflated by HICP – , respectively, and compute their quarterly growth rates. As for the interest rate, we adopt the shadow rate constructed by Krippner (2013), using the quarterly average of monthly values, to account for the constraints imposed by the Effective Lower Bound (ELB).

In the measurement equation, we introduce two types of measurement errors related to two events in our sample. First, our sample includes the COVID-19 outbreak, a major macroeconomic shock that violates the "all fluctuations are alike" principle of Lucas (1977).[6] Without specific treatment of this episode, the slope of the Phillips Curve would appear artificially flat, leading to a biased and downwardly distorted estimate of nominal rigidities. We therefore introduce $\alpha_{y,1}$ and $\alpha_{y,2}$ and $\alpha_{w,1}$ and $\alpha_{w,2}$, calibrated to average out the extreme recession and expansion caused by lockdown policies over those two quarters. Since we exclude 2020 from likelihood calculation, these two additional terms are automatically excluded from the likelihood computation and thus do not directly interfere with the identification of structural parameters.

The second event concerns the period at the Zero Lower Bound (ZLB), which requires the use of a shadow rate that pushes the average interest rate to very low levels. Without treatment, the estimated interest rate would be consistent with a near-one discount factor. We therefore introduce a correction term, $\overline{r}$, in the measurement equation for the interest rate. Given the low nominal rate environment and the presence of trend inflation, this adjustment ensures that the steady-state condition $\frac{\overline{\pi}}{\beta} - 1 + \overline{r}$ aligns with the observed average interest rate, while preserving the restriction $\beta < 1$.

Priors and posteriors estimate in the benchmark model. Table 1 reports the prior and posterior distributions for the estimated parameters. We first focus on the priors and benchmark model's posterior. Priors are chosen based on standard conventions in the literature under the constraint that the model dynamics are far more sensitive to parameter change

[6] In particular, the COVID recession was marked by a sharp contraction in output without a corresponding decline in real wages, largely due to mitigation policies implemented by governments. This disconnect temporarily breaks the empirical relationship underpinning the New Keynesian Phillips Curve.

than their usual linearized counterpart. In all the estimations in the paper, we assume that the discount factor is $\beta = 0.995$, the yearly inflation trend is 2% or $\overline{\pi} = 1.005$, and that the elasticity of good and labor demand are equal to $\varepsilon_p = \varepsilon_w = 9$. The autocorrelation of the monetary policy shock is never identified suggesting we could assume an i.i.d shock and $\rho_r = 0$. Results are not sensitive to change in those parameters but their identification is beyond the scope of this paper.

The standard deviations of the shocks $(\sigma_r, \sigma_d, \sigma_p, \sigma_w)$ are assigned inverse gamma priors with a mean of 0.001. Posterior means remain close to these priors, with, in the absence of the scaling generated by the linearization, higher values for the cost-push shock ($\sigma_p = 0.016$) and labor supply shock ($\sigma_w = 0.031$). The persistence of shocks, modeled through AR(1) parameters, exhibits significant posterior persistence, particularly for the risk premium shock ($\rho_d = 0.991$), the labor supply shock ($\rho_w = 0.9777$), and the price cost-push shock ($\rho_p = 0.988$) with posterior means close to the upper bound of the prior distribution.

The curvature of consumption utility (σ) and the disutility of labor (χ) follow gamma priors with means of 2 and 1, respectively. Posterior mode estimates indicate large increases for σ, with $\sigma = 4.825$ while the estimation for $\chi = 0.089$ implies a nearly linear curvature, as the exponent $1 + \chi$ in the disutility of labor approaches 1. The consumption habit prior follows a beta distribution with a mean at 0.5 and exhibits posterior distribution with a mode at $h = 0.679$.

In terms of the monetary policy rule, the inflation response parameter we found a posterior mean of $\theta_\pi = 1.948$, reflecting a strong monetary policy response to inflation deviations, while the mode of the output response parameter is $\theta_y = 0.111$ and the interest rate smoothing is $\rho = 0.935$, consistent with findings in the literature on interest rate inertia.

Parameters governing the steady-state price and wage stickiness $(\bar{\phi}_p, \bar{\phi}_w)$ are estimated with priors centered at 0.7. We set tight priors consistent with the current practice for modeling the euro area business cycle in order to get a stable solution that is consistent with the micro evidence on wage and price setting. The posterior mode for steady-state price ($\bar{\phi}_p = 0.85$) and wage stickiness ($\bar{\phi}_w = 0.863$) suggest significant rigidities at the steady-state, aligning with standard macroeconomic models. However, the size of the price and wage state dependency parameters ($\gamma_p = 9.280, \gamma_w = 9.715$) show posterior means consistent with priors, supporting the robustness of the model's endogenous wage and price-setting mechanisms. The intensities of choice are not different enough from their prior to claim strong identification, but they are in the realm of the Gasteiger and Grimaud (2023) estimates and the literature on discrete choice models following Matějka (2016). Moreover, the intensities of choice for price state dependency parameter is very close to Gautier et al. (2025) estimated value of a Gasteiger and Grimaud (2023) model estimated on EU micro data. For the indexation parameters with priors centered at 0.5 both prices and wages show values between 0.2 and 0.4, indicating 20% to 40% indexation to last quarter's price inflation.

		Prior Distribution			Benchmark model $\phi_{p,t}$, $\phi_{w,t}$ - Posterior Distribution			Fixed updating freq. model ϕ_p, ϕ_w - Posterior Distribution		
		Shape	Mean	Std	Mode	Mean	[5%:95%]	Mode	Mean	[5%:95%]
Panel A: Shock processes										
Monetary policy shock std	σ_r	$\mathscr{IG}_2$	0.001	1	0.001	0.001	*[0.001:0.001]*	0.001	0.001	*[0.001;0.001]*
Risk premium shock std	σ_d	$\mathscr{IG}_2$	0.001	1	0.002	0.002	*[0.002;0.002]*	0.002	0.002	*[0.002;0.002]*
Cost-push shock std	σ_p	$\mathscr{IG}_2$	0.001	1	0.016	0.017	*[0.014;0.020]*	0.018	0.018	*[0.016;0.022]*
labor supply shock std	σ_w	$\mathscr{IG}_2$	0.001	1	0.031	0.032	*[0.027;0.039]*	0.038	0.041	*[0.033;0.052]*
AR(1), risk premium shock	ρ_d	$\mathscr{B}$	0.5	0.1	0.991	0.990	*[0.983;0.994]*	0.992	0.990	*[0.984;0.994]*
AR(1), cost-push shock	ρ_p	$\mathscr{B}$	0.5	0.1	0.988	0.986	*[0.976;0.992]*	0.993	0.993	*[0.990;0.995]*
AR(1), labor supply shock	ρ_w	$\mathscr{B}$	0.5	0.1	0.977	0.977	*[0.962;0.987]*	0.946	0.937	*[0.911;0.958]*
Panel B: Structural parameters										
Curvature consumption utility	σ	$\mathscr{G}$	2	1	4.825	5.058	*[4.091;6.183]*	4.726	4.786	*[3.785;5.943]*
Curvature disutility of labor	χ	$\mathscr{G}$	2	1	0.089	0.116	*[0.041;0.262]*	0.217	0.200	*[0.076;0.376]*
Consumption habit	h	$\mathscr{B}$	0.5	0.1	0.679	0.673	*[0.595;0.750]*	0.687	0.681	*[0.601;0.762]*
Inflation stance	θ_π	$\mathscr{G}$	2	0.05	1.948	1.940	*[1.856;2.023]*	1.940	1.932	*[1.847;2.016]*
Output stance	θ_y	$\mathscr{G}$	0.125	0.01	0.111	0.111	*[0.095;0.128]*	0.115	0.112	*[0.095;0.128]*
Interest rate smoothing	ρ	$\mathscr{B}$	0.5	0.1	0.935	0.934	*[0.920;0.947]]*	0.938	0.935	*[0.921;0.948]*
Panel C: Price and wage setting										
Price Calvo share	$\bar{\phi}_p$	$\mathscr{B}$	0.7	0.02	0.850	0.848	*[0.828;0.864]*	0.819	0.816	*[0.807;0.823]]*
Intensity of choice price	γ_p	$\mathscr{N}$	10	0.5	9.280	9.323	*[8.436;10.191]*			
Price indexation	ϱ_p	$\mathscr{B}$	0.5	0.1	0.225	0.232	*[0.166;0.301]*	0.162	0.165	*[0.109;0.234]*
Wage Calvo share	$\bar{\phi}_w$	$\mathscr{B}$	0.7	0.02	0.863	0.867	*[0.846;0.886]*	0.805	0.809	*[0.790;0.826]*
Intensity of choice wage	γ_w	$\mathscr{N}$	10	0.5	9.715	9.682	*[8.845;10.538]*			
Wage indexation	ϱ_w	$\mathscr{B}$	0.5	0.1	0.374	0.375	*[0.280;0.473]*	0.376	0.370	*[0.309;0.397]*
Log posteriors						475.923			471.5637	

Table 1: Priors and posteriors of the quantitative models. Sample: 1999Q1-2023Q4

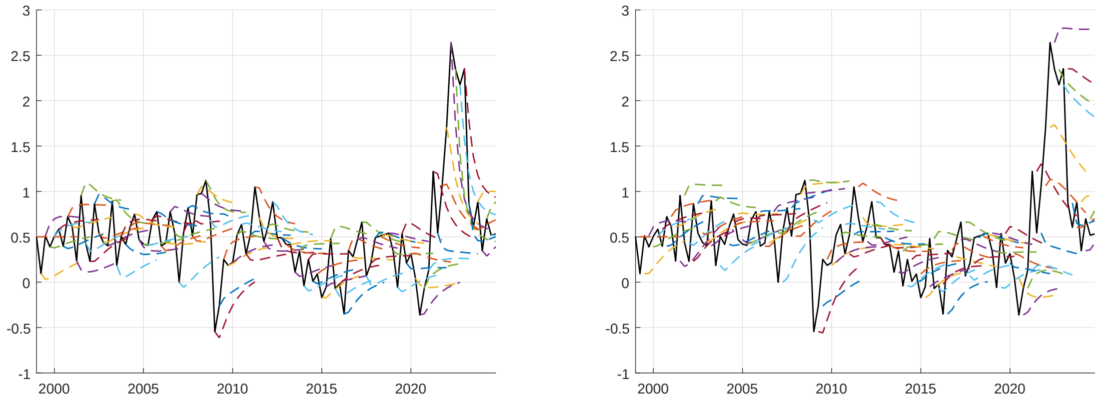
Comparison with the fixed updating frequency model. The log posterior value of the version with fixed updating frequencies is lower than in the quantitative benchmark model with endogenous frequency. This suggests that wage and price indexation help to address some data features, but the full setup with endogenous state dependency outperforms a traditional quantitative DSGE model. To formally compare the two alternative representations of the data, we assume equal prior probabilities over the two competing specifications taking the fixed frequency model as baseline. The Bayes factor is 78 for our specification, which implies the data are approximately 78 times more likely under the benchmark model than under the fixed-frequency model. The posterior probability of our new pricing mechanism is 0.987, it is nearly 99% likely to be the correct specification, relative to the simpler model without state-dependent price and wage setting.

Comparing the parameters in the two quantitative models reveals some differences. First, the standard deviations of labor supply and cost-push shocks are larger in the version with fixed updating frequencies. Hence, without state-dependent wage and price setting, and with relatively flat Phillips curves, the model requires larger supply shocks to match observed price and wage inflation dynamics. Second, the curvature of the disutility of labor, χ, is small in both models but more than twice as large in the version with fixed updating frequencies, making marginal cost steeper.[7] Finally, the wage resetting frequency is smaller in the model with fixed updating frequencies compared to the steady state one of the benchmark model. This is due to the fact that in the absence of time variation, the former does need higher flexiblity to explain the price to wage feedback loop during the inflation surge.

Finally, Figure 5 shows all those effects by plotting the in sample forecast for inflation in both models. Because our contribution focuses on pricing mechanisms, we specifically report the forecast for inflation. Prior to 2020, forecast are relatively similar for both models, as state-dependent price and wage setting mechanisms do not significantly impact the dynamics during this period. This aligns with the view that state dependencies become more pronounced only during periods of high inflation.

Both models struggle to capture the initial inflation surge in the short run and subsequently produce large errors. The benchmark model produces a slightly larger forecast error during the persistent run-up of inflation. This is due to both a lower estimated persistence of cost-push shocks and state-dependency, which makes the economy more flexible, so that the effects of shocks becomes less persistent. However, for the same reasons, the model with fixed updating frequencies yields very large forecast errors in the run-down of inflation. The near-unit-root behavior of supply shocks driving inflation in this model (see Subsection 4.2), combined with flat and autocorrelated NKPCs drive these errors. Indeed, under a time-invariant and flat New Keynesian Phillips Curve (NKPC), interactions between macroe-

[7] In this setup, a larger χ drives a stronger non-linear relationship between output and marginal costs, potentially overstating the steepness of the Phillips curve in normal times. In the *Endogenous Calvo model*, χ plays a critical role in explaining the present value of unions and firms. A large χ in this model would risk creating excessive state dependency.



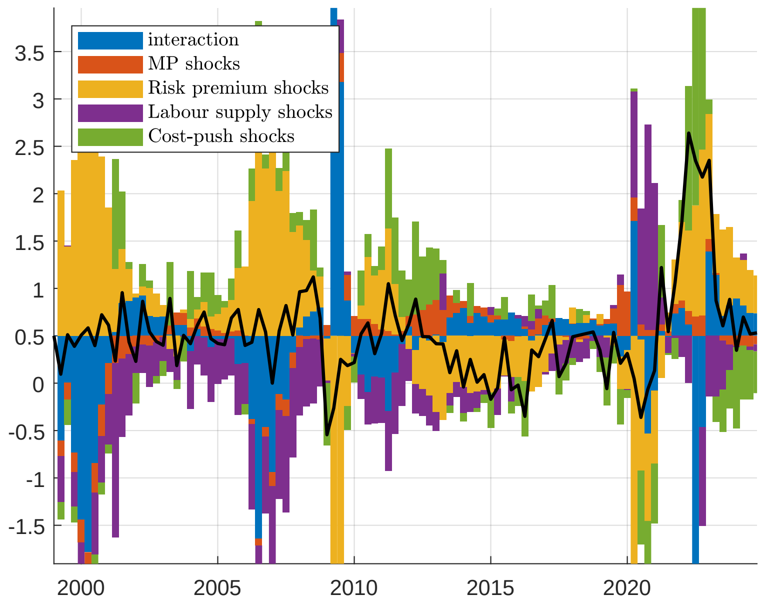
(a) Benchmark (b) Fixed updating frequency

Figure 5: **In sample inflation forecast at the posterior mode** Panel (a): for the benchmark model, Panel (b) for the model with fixed updating frequencies.

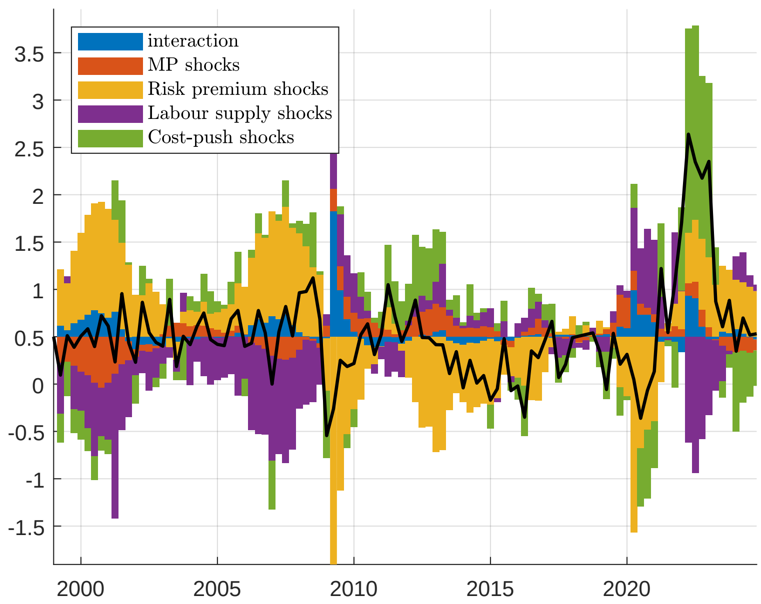
conomic conditions, other aggregate shocks, and inflation are very limited. As a result, in the fixed updating frequency framework, supply shocks persistence account for most of the observed dynamic in inflation. On the contrary, errors are strikingly close to zero for the benchmark model, which takes into account that the higher flexibility of the economy yields a faster adjustment to shocks and more interaction with the rest of macro development.

In order to quantify the inflation forecast errors, we compute the RMSE for four-quarter-ahead inflation forecasts at the posterior mode in both models. Over the full sample, the benchmark model exhibits an RMSE of 0.54, whereas the fixed updating frequency model performs worst, with an RMSE of 0.60. Restricting the sample to the high-inflation period (i.e., 2021Q1–2023Q4), not surprisingly the average error increases, but importantly the gap between the models increases, with the benchmark model yielding an RMSE of 0.97 and the fixed updating frequency model performing worse at 1.16.[8] To further assess the performance of the models, we split the sample based on inflation regimes: a low inflation regime ($100 \times (\pi_t - 1) < 0.25$), a regime with inflation around target ($0.25 < 100 \times (\pi_t - 1) < 0.75$), and a target overshoot regime ($100 \times (\pi_t - 1) > 0.75$). The benchmark model exhibits RMSEs of [0.4991, 0.3927, 0.8727] across the three regimes, respectively. In comparison, the Fixed Updating Frequency model yields RMSEs of [0.5216, 0.4109, 1.0167]. These results indicate that the benchmark model delivers notably better forecasting performance during periods of elevated inflation.

[8]For one-quarter-ahead forecast errors, the results are less clear-cut. The benchmark model exhibits an RMSE of 0.42, whereas the fixed updating frequency model performs marginally better at 0.41. During the high-inflation period, the gap between the models does not widen significantly, with the benchmark model at 0.66 and the fixed updating frequency model at 0.63.



(a) Benchmark



(b) Fixed updating frequencies

Figure 6: **Historical decomposition of price inflation in both model specifications.** Panel (a): HD for the benchmark model, Panel (b) HD for a model with fixed updating frequencies. Notes: The decompositions are obtained by simulating each shock separately and adding them together thereafter. Due to the non-linear nature of the models, the sum of individual effects does not fully reconstruct the endogenous path when all shocks act together. The residual (blue bar) captures non-linear interactions among shocks that cannot be attributed to a single shock in isolation.

4.2 Drivers of inflation in both models

One of our key findings is that for most of the sample the version with time-varying updating frequency explains price and wage inflation by interactions of several shocks. In contrast, the version with fixed updating frequency explains the dynamics with hardly any interaction of shocks. This insight stems from a historical decomposition of inflation dynamics.

The historical decomposition identifies the contributions of the specific shocks to the historical dynamics of the variables. However, due to the non-linear nature of the model, the sum of individual shock effects does not fully reconstruct the endogenous path when all shocks act simultaneously. To address this issue, a residual (blue bar) is included in the decomposition, capturing non-linear interactions among shocks that cannot be attributed to a single shock in isolation.[9]

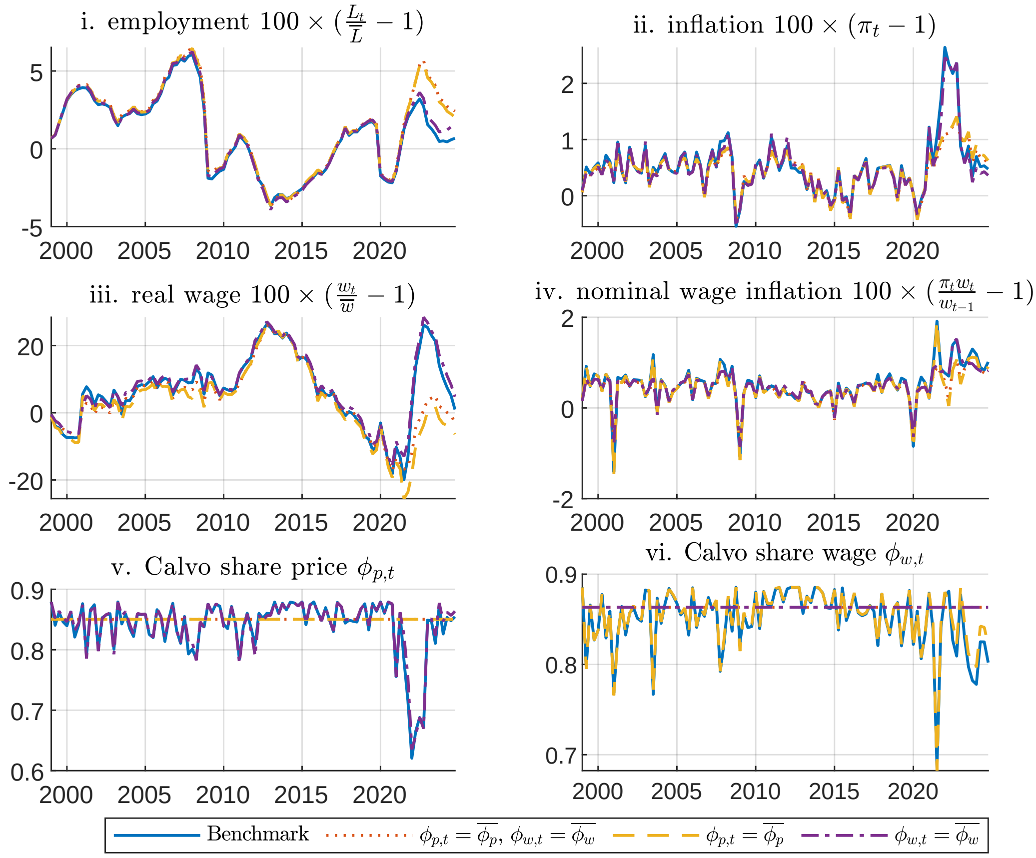
Figure 6 highlights striking differences between the two versions of the model. The inflation decomposition in the version with time-varying updating frequencies in Figure 6a shows that for most of the sample, inflation is not just explained by supply-side shocks. Shock interactions play an important role, which reflects a high degree of non-linearity in this version of the model. Moreover, this version also attributes a notable role to demand-side shocks. While supply-side shocks are predominant at the onset of the recent surge in inflation, the persistence of inflation appears to have been supported by subsequent demand shocks. The mechanism driving this episode is as follows: the initial cost-push shock steepened the Phillips curves, while demand shocks contributed to the amplification of the inflationary impact of supply-side shocks due to a stronger price-wage interaction.

In comparison, the historical inflation decomposition in the version with fixed updating frequencies in Figure 6b attributes hardly any role to shock interactions. Prior to 2021, inflation is primarily driven by demand-side and labor supply shocks, with cost-push shocks contributing to short-term, high-frequency fluctuations. In the post-pandemic period, inflation is largely explained by cost-push shocks, which account for roughly two-thirds of the total. Positive demand-side shocks play a more limited role, contributing approximately one-third relative to the benchmark model. Similar insights can be gained from the wage inflation decomposition of this version of the model relegated to Figure F.4 of Appendix F.

4.3 Inflation channels in the benchmark model

We now turn to counterfactuals that demonstrate the crucial role of time-varying price- *and* wage-updating frequencies in explaining euro area data from 2021 onwards. Figure 7 reports the benchmark simulation with time-varying price- and wage-adjustment frequencies (blue

[9] This residual reflects the complexity of non-linear dynamics and varies based on the specific shocks and the model's state-dependent structure. Its presence highlights a key limitation: the decomposition is inherently imperfect and should be interpreted as an approximation rather than a definitive breakdown of drivers. As model non-linearity increases, interaction terms become more significant, further reducing the clarity of the decomposition.



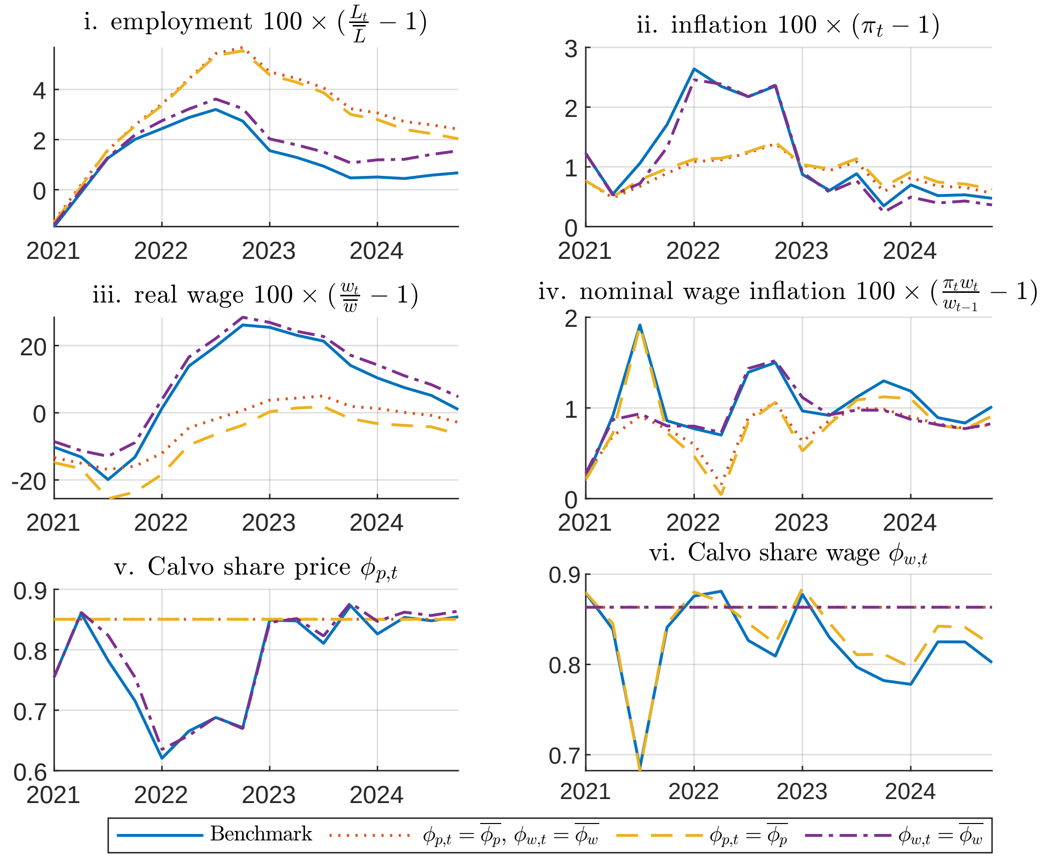
(a) Full sample

Figure 7: **Contribution of state-dependent price and wage setting to the dynamics of selected variables.** Counterfactual exercise switching off the state dependency in wage and/or price setting. Dotted red lines: fixed updating frequencies, dashed yellow lines: only *wage* updating frequency is time-varying, dash-dotted purple lines: only *price* updating frequency is time-varying. We refer to the share of non-reoptimized wages or prices displayed in the chart as the Calvo shares.

solid line, coinciding with the data by construction) next to the counterfactuals. The red dotted line is the counterfactual with both adjustment frequencies fixed. The yellow dashed line is the counterfactual with time-varying wage-adjustment only. Finally, the purple dash-dotted line is the counterfactual with time-varying price-adjustment frequency only.

Panel 7a exhibits the simulated paths for all scenarios over the entire sample. Up to 2021, the counterfactual predicted paths deviate only slightly from the data. This suggests that time-varying price- and wage-adjustment frequencies play only a minor role in explaining the data during the pre-2021 period. The adjustment frequencies show only little variation around their posterior mode in the benchmark as well in the counterfactual simulations.

However, Panel 7b makes clear that time-varying price- *and* wage-adjustment frequencies play a crucial role in explaining the data from 2021 onwards. On the one hand, to generate the surge in inflation, as well as the dynamics of employment and the real wage,



(b) Recent sample

Figure 7: (Cont.) **Contribution of state-dependent price and wage setting to the dynamics of selected variables.** Counterfactual exercise switching off the state dependency in wage and/or price setting. Dotted red lines: fixed updating frequencies, dashed yellow lines: only *wage* updating frequency is time-varying, dash-dotted purple lines: only *price* updating frequency is time-varying. We refer to the share of non-reoptimized wages or prices displayed in the chart as the Calvo shares.

the model relies to a large extent on the time-varying price-adjustment frequency, which seems relatively more important than endogenous wage setting frequency. In particular, state-dependent wage setting alone cannot capture the dynamics of nominal wage inflation and real wages from 2022 onward. On the other hand, to capture the initial spike in nominal wage inflation at the end of 2022, the model depends crucially on the time-varying wage-adjustment frequency. Thus, the model relies crucially on the interaction of time-varying price- *and* wage-adjustment frequencies to explain the data during times of large shocks. Finally, without this mechanism the model fails to explain the data (red dotted lines).

Finally, we compare Figure 7a (Panel (v)) to Gautier et al.'s (2025) euro are price setting frequency data, based on CPI micro data from 2012 to 2024. Strikingly, the model-generated share of non-reoptimized prices closely aligns with the data. Before the 2021-2022 inflation surge, these shares are around 0.85 (model) and 0.77 (data). Around 2021Q3 in the model and 2022Q1 in the data, it drops to approximately 0.65. This consistency suggests that our model captures key features of price rigidity during the recent inflation episode.[10]

5 Policy implications

Next, we analyze the policy implications of our model. We investigate three main questions. First, we examine how the transmission of shocks varied over the sample period, depending on the state of the business cycle and the estimated shocks. Second, we ask what the outcome would have been under alternative monetary policy choices. We also investigate whether time-varying price and wage adjustment frequencies can help explain the recently observed soft landing.

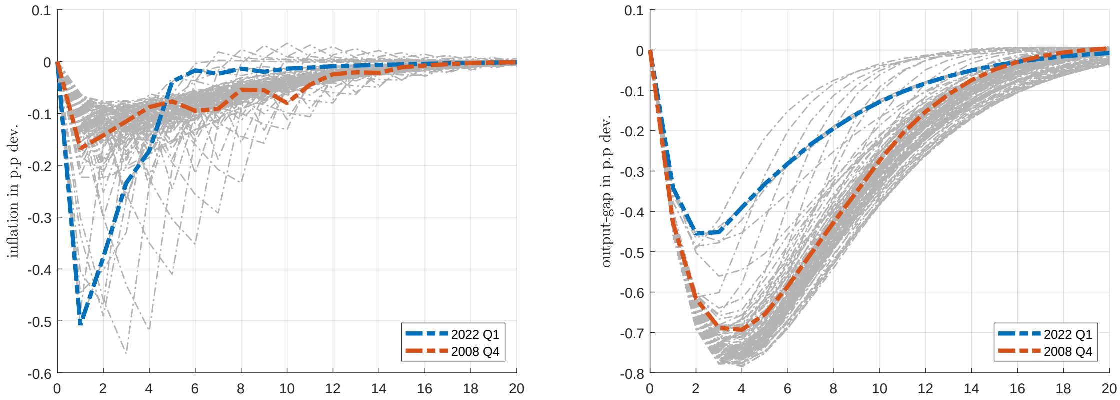
5.1 Shock transmission over the business cycle

We now examine how the transmission of shocks varied conditional on the euro area business cycle, i.e., conditional on the filtered shocks from the estimated quantitative model. First, we focus on monetary policy shocks and then we look at supply shocks. To compute IRFs conditional on the business cycle, we simulate the path of the endogenous variables in our model, in response to the filtered shocks, which provides the observed data. We then run a second simulation, adding a monetary policy (or a cost-push) shock of fixed size to the filtered shocks for each quarter in the sample. The difference between these two simulations yields the IRFs to the monetary policy (or cost-push) shock conditional on the business cycle. Hence, for each quarter in our sample, we obtain a different IRF to the same shock, allowing us to analyze how the transmission of these shocks varied over time along the euro area business cycle. Note that a linearized version of the model (e.g., Smets and Wouters, 2007), these IRFs would all be identical, while in the nonlinear version IRFs are state-dependent.

Figure 8 shows the responses of inflation and output to a contractionary monetary policy shock for each quarter, highlighting the IRFs corresponding to periods associated with the peak and trough of quarterly inflation. This figure nicely visualizes how the effects of monetary policy shocks in the euro area differed in our sample according to our estimates. In 2008Q4 – orange dashed line – a monetary policy would have had a strong contractionary impact on output with little effect on inflation. In contrast, during the peak of the recent inflation surge, in 2022Q1, a contractionary monetary policy shock would have largely affected inflation and much less output.

These differing IRFs naturally translate into a state-dependent inflation-output stabilization trade-off, summarized by Figure 9. Panel 9a presents the path of quarterly HICP inflation in the euro area (solid blue line, scale on the left axis) alongside the trough response

[10] Arguably the comparison is not ideal. First, the Gautier et al. (2025) series excludes energy prices, while our model-generated share is based on headline HICP. Second, the Gautier et al. (2025) series measures unchanged prices, whereas ours is the share of non-reoptimzed (but possibly changed) prices due to price indexation.



(a) Inflation responses (b) Output responses

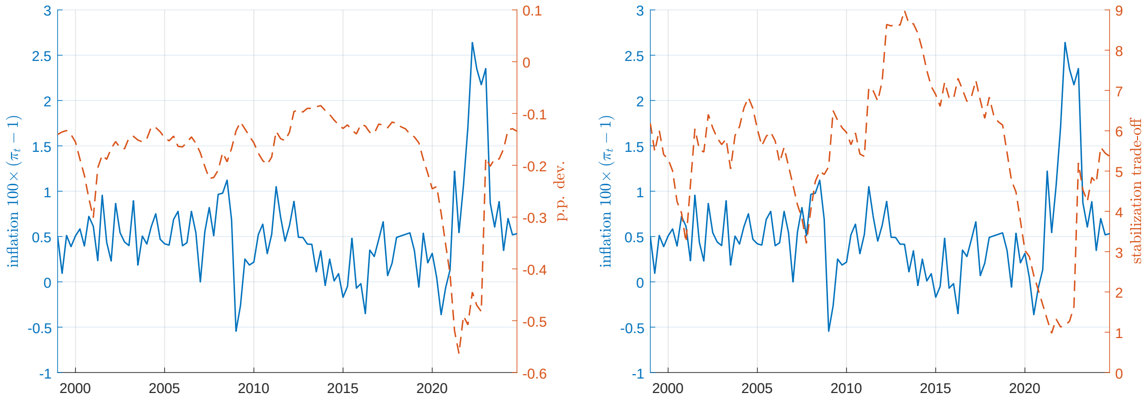
Figure 8: **IRFs to a + 0.25% monetary policy shock as function of the state** Panel (a): Inflation. Panel (b): Output. State-dependent IRFs are calculated by comparing the IRFs from all filtered shocks, with the IRFs from those filtered shocks plus an additional contemporaneous monetary policy shock. This isolates the effect of the monetary policy shock conditional on the initial state.

of inflation along the IRFs (dashed red line, scale on the right axis) to a fixed-size contractionary monetary policy shock. The trough of the IRFs is simply the minimum inflation response over all quarters of the IRFs. The results indicate that inflation declines more sharply in response to a contractionary monetary policy shock when initial inflation is high.

Panel 9b goes one step further, and examines the inflation-output trade-off over time. Here, the dashed red line represents the sum over 20 quarters of the ratio of the IRFs of the output gap to inflation, effectively capturing the cost of reducing inflation in terms of output. We find that, when inflation is high, the trade-off improves substantially, making it less costly to bring inflation down. In contrast, when inflation is low, the trade-off worsens, implying higher output costs to achieve the same reduction in inflation. These findings are consistent with the intuitions developed in the context of the small model in Section 3. The mechanism behind this pattern is that high inflation raises the relative benefit of adjusting prices for firms and wages for unions, leading to more frequent price and wage adjustments. This increased flexibility steepened the price and wage Phillips curves during the recent inflation surge in the euro area. In consequence, the effects of monetary policy shocks on inflation were stronger, and the inflation-output trade-off - in response to monetary policy shocks - improved. Put differently, the increase in the frequency of adjustment appears to have made it less costly to reduce inflation for the ECB during the post-pandemic inflation surge. In contrast, as inflation started to decline as of 2023, the trade-off increased again.

Next, we turn to the transmission of cost-push (supply-side) shocks (Figure 10).[11] For

[11] Figure F.3 show the responses of inflation and output to an inflationary cost-push shock for each quarter, as Figure 8 does for monetary policy shocks.

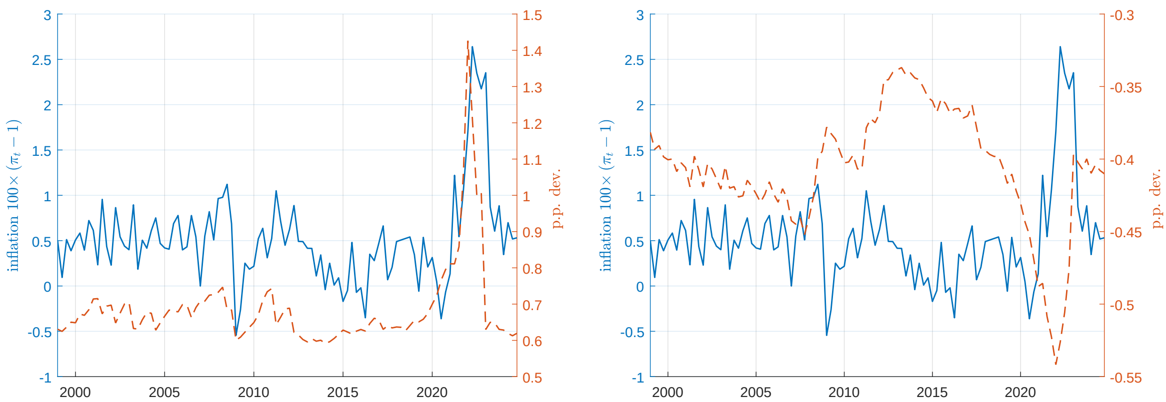


(a) Trough response of inflation

(b) Stabilization trade-off

Figure 9: **State-dependent inflation and stabilization trade-off responses to 0.25% contractionary monetary policy in the euro area over the business cycle.** Panel (a) Solid blue line is HICP inflation, scale on the left axis; dashed red line is the trough response of inflation along the IRFs, scale on the right axis. Panel (b): Solid blue line is HICP inflation, scale on the left axis; dashed red line is the the stabilization trade-off along the IRFs, scale on the right axis.

Notes: Stabilization trade-off is computed as the sum over 20 quarters of the ratio of the IRFs of output gap divided by the sum of the IRFs of inflation in response to a 0.25% monetary policy shock.



(a) Peak response of inflation

(b) Average real wage deviation

Figure 10: **State-dependent inflation and average real wage responses to a 0.5% cost-push shock in the euro area over the business cycle.** Panel (a): Solid blue line is HICP inflation, scale on the left axis; dashed red line is the peak response of inflation along the IRFs, scale on the right axis. Panel (b): Solid blue line is HICP inflation, scale on the left axis; dashed red line is the average real wage deviation from steady state over 20 quarters IRFs, scale on the right axis.

this analysis, we repeat the above exercise, using a fixed-size cost-push instead of a monetary policy shock. Specifically, we compute the IRFs as the difference between a simulation using the filtered shocks alone and one with the addition of a cost-push shock for each period in the sample. In Panel 10a, the peak response of inflation to the cost-push shock is shown in dashed red, while the observed inflation data are in solid blue. We find that cost-push shocks have a stronger effect on inflation when inflation is high. The steepening of the price and wage Phillips curves at the onset of the inflation surge therefore likely made cost-push shocks more inflationary, such that the nonlinearity amplified the initial rise in inflation.

Panel 10b reports the average real wage deviation over 20 periods (red dashed line) conditional on the business cycle, in response to a cost-push shock. When inflation (solid blue line) is around 0.5%, the average real wage deviation is around -0.4%. When inflation is even lower, the value increases to around -0.33% reflecting a stronger response of nominal wages relative to prices. However, during episodes of high inflation, the response of nominal wages relative to prices is weaker, while prices react strongly. Finally, as inflation declines, the response of nominal wages relative to prices becomes stronger. These findings can be rationalized by the very same mechanism as discussed right above (see Panel (b) in Figure 7). Price- and wage-adjustment frequencies are at the heart of the mechanism. As can be seen in Panels (v.) and (vi.) in Figure 7, the price-adjustment frequency rose sharply during 2021 and 2022 leading to relatively weaker responses of nominal wages. The wage-adjustment frequency increased more gradually and persistently, while the price-adjustment frequency already declined in 2023. Put differently, in the euro area, price inflation accelerated before wage inflation, initially leading to a sharp decrease in real wages in 2021 that was only gradually reversed.

5.2 Policy stance and stabilization trade-offs

This section examines how the shape of the price and wage Phillips curves influences the trade-off between inflation and output, and how this can lead to different macroeconomic outcomes under alternative monetary policy stances. Counterfactual simulations are used to illustrate how recent dynamics might have evolved under different policy settings.

Specifically, in this subsection, we investigate how policy counterfactuals change between models with endogenous and fixed price and wage adjustment frequencies. Figure 11 compares the effects of different monetary policy stances toward inflation for the output gap, inflation, nominal wage inflation, and the policy rate. Solid lines represent the paths of variables when all parameters are at the posterior mode, i.e., the baseline scenarios. By construction, the simulated paths coincide with the data in both cases.

The counterfactual simulations during the 2021Q1–2024Q4 period use the same model-specific filtered shocks as in the baseline scenarios. However, the counterfactuals consider inflation reaction coefficients (θ_π) adjusted by $\pm 10\%$.[12]

Under a tighter monetary policy stance ($\theta_\pi + 10\%$, dashed lines), the two models ex-

[12] To save space, we omit the pre-2021 period, where no significant deviations are observed.

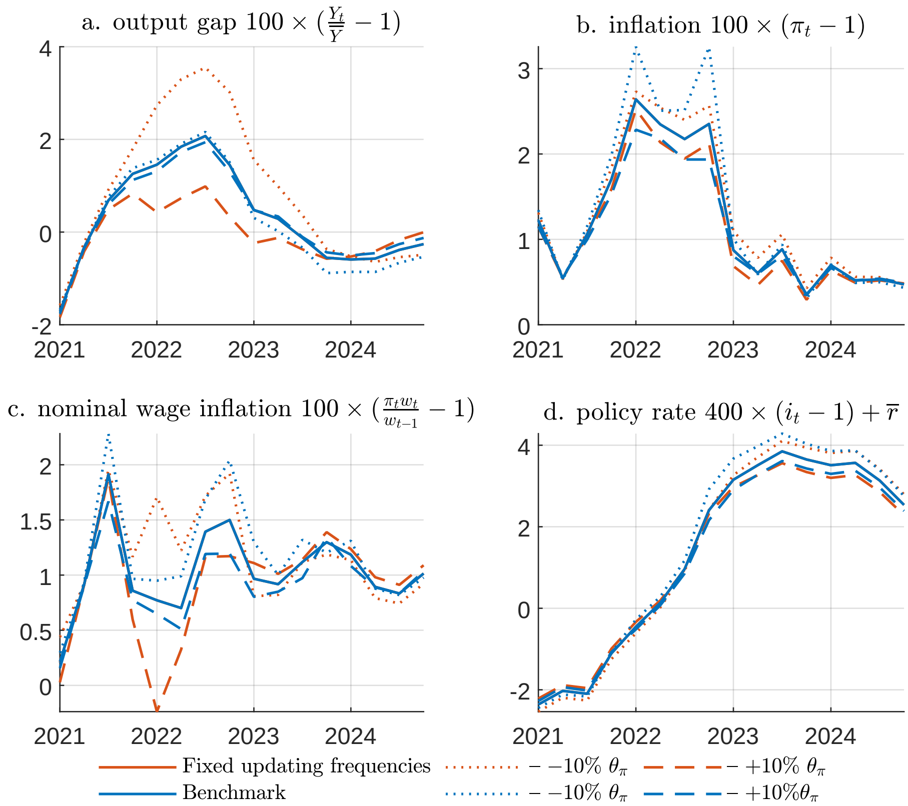


Figure 11: **Impact of the monetary policy stance on output and inflation in the euro area recent inflation surge.** Counterfactual exercise varying the monetary policy stance in the benchmark and fixed updating frequencies models. Red lines: fixed updating frequencies, blue lines: benchmark model. Dotted lines: decrease of the inflation reaction coefficient in the Taylor rule parameter by 10%, Dashed lines: increase of the same parameter by 10%.
Notes: Counterfactual simulations in the benchmark model (blue lines) and the model with fixed adjustment frequencies (red lines) during the 2021Q1-2023Q4 period, with different monetary policy stance. The dotted lines correspond to cases with a change −10% to the estimated reaction of the deviation of inflation to the target in the Taylor rule, the dashed lines are cases with a change +10% to the same parameter.

hibit markedly different outcomes. In this counterfactual, both models predict comparable price inflation, as expected, below the baseline.[13] However, in the model with fixed adjustment frequencies (red lines), the slight decrease in inflation comes at the cost of generating a longer-lasting recession with a more persistent negative output loss relative to the benchmark model (blue lines), whose output gap behavior, instead, almost coincides with the baseline. In sum, the model with fixed adjustment frequencies predicts a less favorable output-inflation trade-off, i.e., flatter Phillips curves relative to the benchmark model. Therefore this model suggests that a more aggressive monetary policy would have led to a deeper recession during this episode of high inflation. In contrast, the benchmark model predicts that a more aggressive monetary policy stance could have reduced price and wage inflation by more during this episode of high inflation with only limited additional output cost. The latter is true, because in the benchmark model the Phillips curves are steeper when

[13] At times, the model with fixed adjustment frequencies predicts lower wage inflation than the benchmark.

inflation is high, which improves the output-inflation trade-offs.

Finally, notice from Figure 11 that the counterfactual with a more passive monetary policy stance ($\theta_\pi - 10\%$, dotted lines), suggests opposite conclusions compared to a more aggressive monetary policy stance. The model with fixed adjustment frequencies predicts a counterfactual expansion at the cost of moderately higher price and wage inflation. In contrast, the benchmark predicts hardly any difference in output relative to baseline, but much higher price and wage inflation.

The takeaway from these counterfactuals is that, through the lens of the benchmark model, a more proactive monetary policy during 2021Q1–2024Q4 could have helped moderate inflation with relatively minimal impact on output. In contrast, a more dovish monetary policy would have led to higher inflation.[14]

The difference in monetary policy effectiveness between the two models, just described above, would affect the optimal policy prescriptions. Appendix E extends the analysis by considering a real-time optimal strict inflation targeting exercise, revealing the following important differences across the two models. The fixed-updating frequency model implies highly persistent inflation, due to persistent cost-push shocks, and a flat Phillips curve. Hence, it calls for an aggressive tightening during the 2021–2022 inflation surge, resulting in substantial output losses with very limited initial impact on inflation. As policy becomes more persistent and slack builds up, disinflationary effects start to appear by 2023. In contrast, the benchmark model views inflation shocks as shorter-lived and inflation less persistent. As a result, it calls for a tightening, that it is slightly above, but aligns closely with actual observed policy. The steeper Phillips curve in this model improves the effectiveness of monetary policy, resulting in significantly lower inflation and a smaller loss in output compared to the fixed-updating frequency model.

6 Conclusion

The findings of this paper highlight the crucial role of state-dependent price and wage-setting frequencies in shaping inflation dynamics and monetary policy trade-offs during the high inflation period. Unlike standard New Keynesian models with quasi-linear Phillips curves, our framework captures non-linear inflation responses when the economy is hit by large shocks. Endogenous price and wage-setting adjustment leads to steeper Phillips curves during periods of high inflation, and it has strong policy implications. State dependency alters the stabilization trade-off, making monetary policy more effective in curbing inflation when inflation is already elevated, but less so in low-inflation environments.

[14] A caveat is that the analysis primarily captures nonlinearities in price and wage setting, while abstracting from other potentially relevant sources of nonlinearity — such as financial frictions — which could influence the inflation-output trade-off and alter the effects of alternative policy stances, possibly in the opposite direction. More broadly, the analysis does not account for the elevated real-time uncertainty that characterized the period, including the economic effects of the COVID-19 pandemic and Russia's invasion of Ukraine.

Our empirical analysis, based on euro area data from 1999 to 2024, reveals that standard models relying primarily on exogenous supply shocks fail to fully explain inflation dynamics. Instead, we show that the interaction between demand and supply shocks is strongly state-dependent, with inflationary supply shocks triggering more frequent price and wage adjustments than disinflationary ones. This asymmetry, driven by firms' and unions' incentives to avoid being locked into unfavorable price or wage levels, plays a critical role in shaping inflation persistence and the transmission of shocks to the broader economy.

Beyond its direct implications for monetary policy, our methodology offers a flexible and scalable framework that can be embedded in larger DSGE models. By capturing the endogenous interaction between price- and wage-setting frequencies in a reduced-form, state-dependent setup, our approach provides a computationally efficient alternative to a fully microfounded menu cost model. This enables the integration of state-dependent inflation dynamics into more complex macroeconomic environments without significantly increasing model complexity.

Overall, our results suggest that monetary policy in the euro area could have responded more aggressively to the recent surge in inflation without incurring excessive output losses. This is due to the increased flexibility in price and wage setting during high inflation periods. Future research should further investigate how state-dependent inflation dynamics influence broader DSGE used for policy evaluation, where additional nonlinearities might hinder or improve stabilization trade-offs.

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A Derivations of the present values of the firms

We assume that each firm i in every period either updates the price optimally, $P^{\#}_{i,t}$, or believe to update the price to the average old price, $P^{f}_{i,t}$. By symmetry, we have $P^{x}_{i,t} = P^{x}_{t}$ for $x \in \{\#, f\}$. From the FOC conditions, the value of a firm of type x is

$$
\begin{aligned}
V^{x}_{p,t|t} &= \mathbb{E}_t \left\{ \sum_{j=0}^{\infty} \left(\prod_{k=0}^{j} \phi_{p,t+k} \right) \phi^{-1}_{p,t} \Lambda_{t,t+j} \left[\left(\frac{P^{x}_{t}}{P_{t+j} \Pi^{-\varrho_p}_{t,t+j}} \right)^{1-\epsilon_p} - p_{w,t+j} \left(\frac{P^{x}_{t}}{P_{t+j} \Pi^{-\varrho_p}_{t,t+j}} \right)^{-\epsilon_p} \right] Y_{t+j} \right\} \\
&= \mathbb{E}_t \left\{ \sum_{j=0}^{\infty} \left(\prod_{k=0}^{j} \phi_{p,t+k} \right) \phi^{-1}_{p,t} \Lambda_{t,t+j} \left[\left(\frac{P^{x}_{t}}{P_t} \frac{P_t}{P_{t+j} \Pi^{-\varrho_p}_{t,t+j}} \right)^{1-\epsilon_p} - p_{w,t+j} \left(\frac{P^{x}_{t}}{P_t} \frac{P_t}{P_{t+j} \Pi^{-\varrho_p}_{t,t+j}} \right)^{-\epsilon_p} \right] Y_{t+j} \right\} \\
&= \mathbb{E}_t \left\{ \sum_{j=0}^{\infty} \left(\prod_{k=0}^{j} \phi_{p,t+k} \right) \phi^{-1}_{p,t} \Lambda_{t,t+j} \left[\left(\frac{p^{x}_{t}}{\Pi_{t,t+j} \Pi^{-\varrho_p}_{t,t+j}} \right)^{1-\epsilon_p} - p_{w,t+j} \left(\frac{p^{x}_{t}}{\Pi_{t,t+j} \Pi^{-\varrho_p}_{t,t+j}} \right)^{-\epsilon_p} \right] Y_{t+j} \right\},
\end{aligned}
$$

where we define the relative price $p^{x}_{t} \equiv P^{x}_{t}/P_t$. Next, we split $V^{x}_{p,t|t}$ into

$$
V^{x}_{p,t|t} = V^{x}_{p,x_2,t|t} - V^{x}_{p,x_1,t|t},
$$

where

$$
\begin{aligned}
V^{x}_{p,x_1,t|t} &\equiv \mathbb{E}_t \left\{ \sum_{j=0}^{\infty} \left(\prod_{k=0}^{j} \phi_{p,t+k} \right) \phi^{-1}_{p,t} \Lambda_{t,t+j} \left(\frac{p^{x}_{t}}{\Pi_{t,t+j} \Pi^{-\varrho_p}_{t,t+j}} \right)^{1-\epsilon_p} Y_{t+j} \right\} \qquad \text{and} \\
V^{x}_{p,x_2,t|t} &\equiv \mathbb{E}_t \left\{ \sum_{j=0}^{\infty} \left(\prod_{k=0}^{j} \phi_{p,t+k} \right) \phi^{-1}_{p,t} \Lambda_{t,t+j} p_{w,t+j} \left(\frac{p^{x}_{t}}{\Pi_{t,t+j} \Pi^{-\varrho_p}_{t,t+j}} \right)^{-\epsilon_p} Y_{t+j} \right\}
\end{aligned}
$$

Next, recall the definitions of the auxiliary variables $x_{1,t}$ and $x_{2,t}$. Thus, we obtain

$$
V^{x}_{p,t|t} = p^{x,1-\epsilon_p}_{t} x_{2,t} - p^{x,-\epsilon_p}_{t} x_{1,t}.
$$

B Derivations of the present values of the unions

We assume that each union l in every period either updates the wage optimally, $W^{\#}_{i,t}$, or, assume to update the wage to the average old wage $W^{f}_{i,t}$. By symmetry, we have $W^{x}_{i,t} = W^{x}_{t}$ for $x \in \{\#, f\}$. Thus the value of a of type x is

$$
V^{x}_{w,t|t} = \mathbb{E}_t \left\{ \sum_{j=0}^{\infty} \left(\prod_{k=0}^{j} \phi_{w,t+k} \right) \phi^{-1}_{w,t} \Lambda_{t,t+j} \left(W^{x}_{t} - MRS_{t+j} \right) L_{x,t+j|t} P^{-1}_{t+j} \Pi^{\varrho_w}_{t,t+j} \right\}.
$$

with demand for the firm's good given by

$$
l_{x,t+j|t} = \left(\frac{W^{x}_{t}}{W_{t+j}} \right)^{-\epsilon_w} L_{d,t+j}.
$$

Eliminating $L_{x,t+j|t}$ yields

$$V^x_{w,t|t} = \mathbb{E}_t\left\{\sum_{j=0}^{\infty}\left(\prod_{k=0}^{j}\phi_{w,t+k}\right)\phi^{-1}_{w,t}\Lambda_{t,t+j}\left[W^x_t - MRS_{t+j}\right]\left(\frac{W^x_t}{W_{t+j}}\right)^{-\epsilon_w} L_{d,t+j}P^{-1}_{t+j}\Pi^{\varrho_w}_{t,t+j}\right\}$$

$$= \mathbb{E}_t\left\{\sum_{j=0}^{\infty}\left(\prod_{k=0}^{j}\phi_{w,t+k}\right)\phi^{-1}_{w,t}\Lambda_{t,t+j}\left[W^{x,1-\epsilon_w}_t W^{\epsilon_w}_{t+j}P^{-1}_{t+j}L_{d,t+j}\Pi^{\varrho_w}_{t,t+j} - mrs_{t+j}W^{x,-\epsilon_w}_t W^{\epsilon_w}_{t+j}L_{d,t+j}\Pi^{\varrho_w}_{t,t+j}\right]\right\}$$

Next, we split $V^x_{w,t|t}$ into

$$V^x_{w,t|t} = V^x_{w,f_2,t|t} - V^x_{w,f_1,t|t},$$

where

$$V^x_{w,f_1,t|t} \equiv \mathbb{E}_t\left\{\sum_{j=0}^{\infty}\left(\prod_{k=0}^{j}\phi_{w,t+k}\right)\phi^{-1}_{w,t}\Lambda_{t,t+j}mrs_{t+j}W^{x,-\epsilon_w}_t W^{\epsilon_w}_t L_{d,t+j}\Pi^{\varrho_w}_{t,t+j}\right\} \quad \text{and}$$

$$V^x_{w,f_2,t|t} \equiv \mathbb{E}_t\left\{\sum_{j=0}^{\infty}\left(\prod_{k=0}^{j}\phi_{w,t+k}\right)\phi^{-1}_{w,t}\Lambda_{t,t+j}W^{x,1-\epsilon_w}_t W^{\epsilon_w}_t P^{-1}_{t+j}L_{d,t+j}\Pi^{\varrho_w}_{t,t+j}\right\}$$

recursively we have

$$V^x_{w,f_1,t|t} \equiv W^{x,-\epsilon_w}_t \times F_{1,t} \qquad \text{and}$$
$$V^x_{w,f_2,t|t} \equiv W^{x,1-\epsilon_w}_t \times F_{2,t}$$

multiplying by $\frac{P_t^{\varepsilon_p}}{P_t^{\varepsilon_p}}$ and $\frac{P_t^{1-\varepsilon_p}}{P_t^{1-\varepsilon_p}}$ we can express all parts in real terms

$$V^x_{w,f_1,t|t} \equiv w^{x,-\epsilon_w}_t \times f_{1,t} \qquad \text{and}$$
$$V^x_{w,f_2,t|t} \equiv w^{x,1-\epsilon_w}_t \times f_{2,t}$$

As in the previous section we obtain

$$V^x_{w,t|t} = w^{x,1-\epsilon_w}_t f_{2,t} - w^{x,-\epsilon_w}_t f_{1,t}.$$

C Effect of trend inflation

From the steady-states $\overline{\phi}_p$, and wages, $\overline{\phi}_w$, we can derive the associated resetting costs, τ_p and τ_w. Assuming a constant steady-state labor supply of $\overline{L} = 1$ and setting τ_p and τ_w to their posterior mode, we compute the model's deterministic steady state as a function of the trend inflation rate ($\overline{\pi}$). Figure C.1 presents the impact of change in trend inflation on selected values of the deterministic steady state.

The model predicts that higher steady-state inflation increases the frequency of both wage and price adjustment – reducing $\phi_{p,t}$ and $\phi_{w,t}$, see Panel (a) – leading to a more flexible economy. The mechanism is intuitive: the higher the trend inflation, the quicker inflation erodes the relative price of non-resetting firms. As a result, a price-resetting firm in the standard Calvo model would fix a higher price (see the discussion in Ascari and Sbordone, 2014)

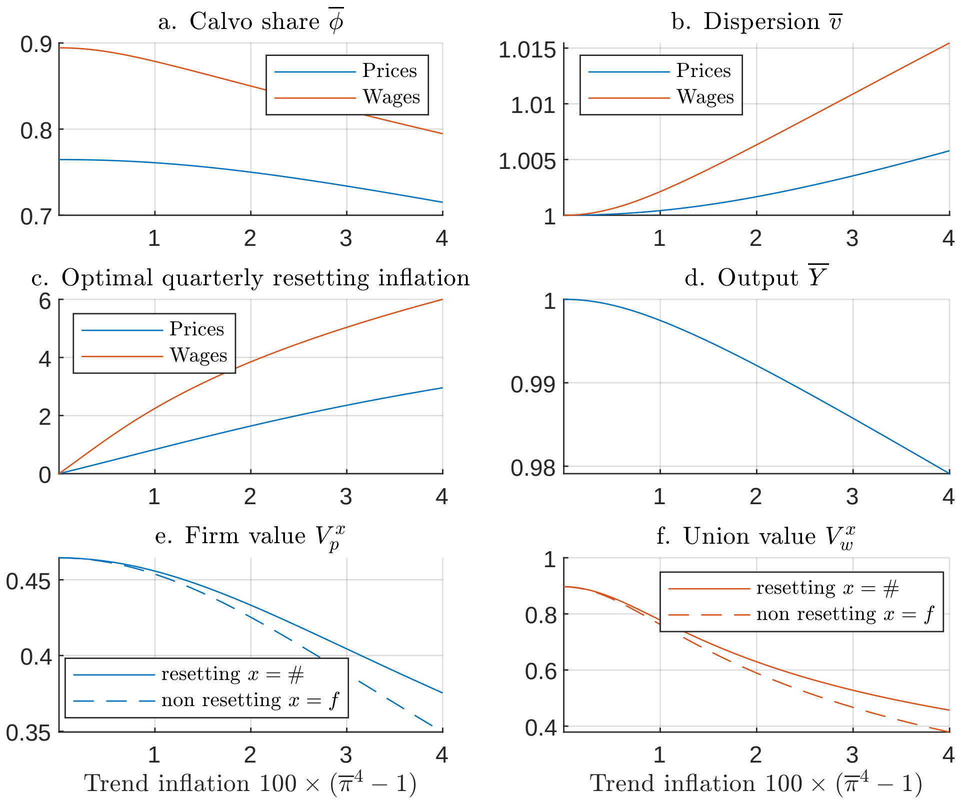
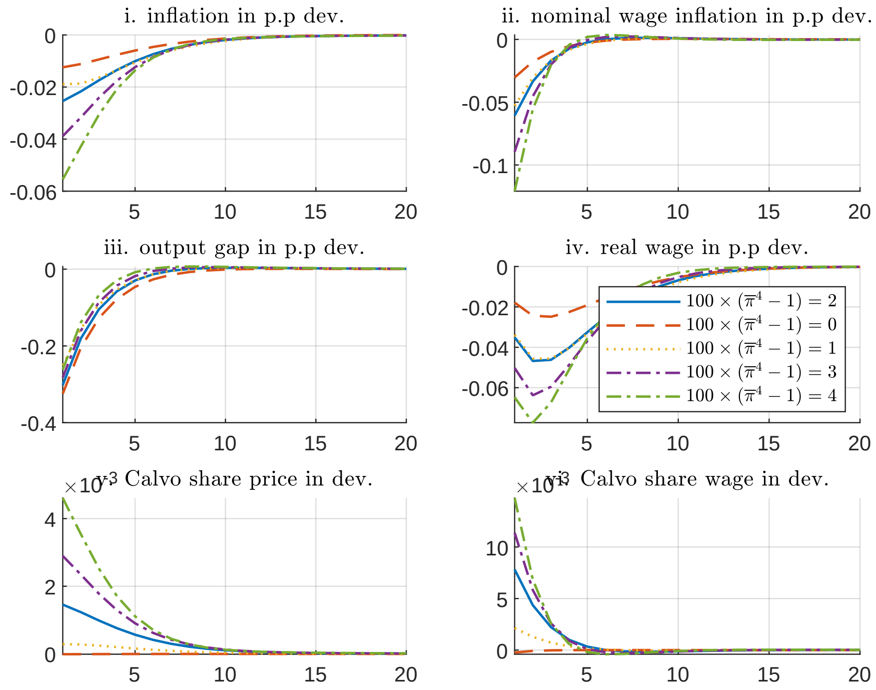


Figure C.1: **Trend inflation and steady state.** The Panels show the effect of trend inflation on the steady-state values of variables related to price (blue lines) and wage (red lines) setting, price and wage dispersion, and output. Dashed lines in Panels (e) and (f) refer to the present value of a non-resetting firm (union) that keeps the price at the average price (wage) level.

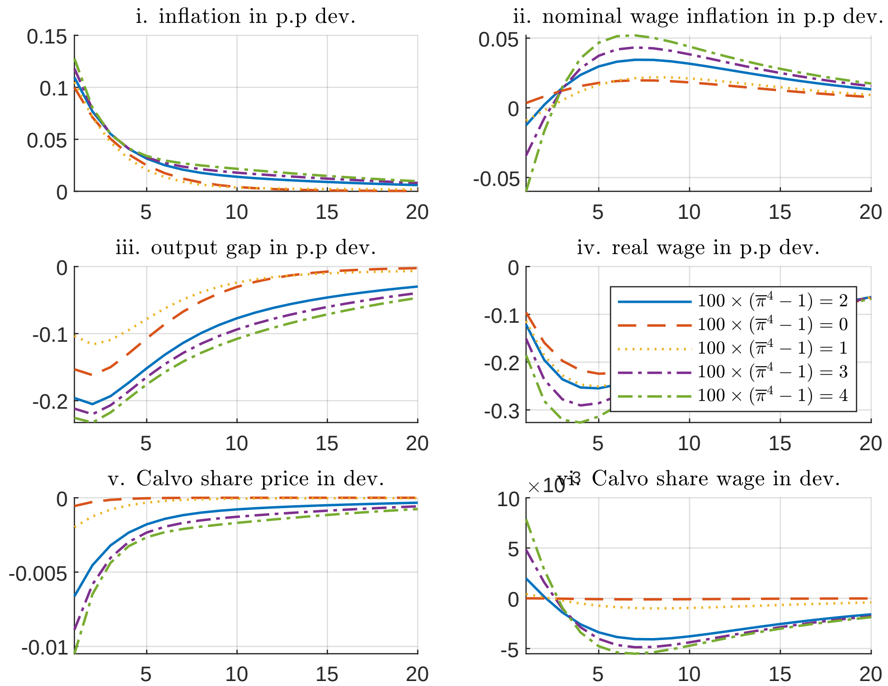
to take into account the trend in the average price level. However, if firms had the option, they would instead choose to adjust prices more frequently, as happens in our model. The same holds for wages and unions. Higher trend inflation widens the gap between firms and unions that reset their prices or wages and those that do not (see Panel (e)). As a result, the opportunity cost of non-resetting prices and wages increases, leading to a higher fraction of firms and unions choosing to reset their wages and prices. While the present values of firms and unions decrease with higher trend inflation, it is the increasing difference between the values of resetting versus holding prices and wages constant that drives the higher frequency of price and wage adjustments. Appendix F, Figure C.2, shows how these changes in first moments extend to second moments in the IRFs.

This main feature of our model is both quantitatively and qualitatively consistent with results from the literature. Indeed, following L'Huillier and Schoenle (2024), we can calculate the best fitting linear steady-state relationship $f_t = \beta_0 + \beta_1 \overline{\pi} + \varepsilon_t$, where f_t is the steady-state average monthly frequency of price changes in percent[15], and $\overline{\pi}$ the net annualized trend inflation, also in percent, implied by Panel (a) in Figure C.1. Using the parameter set calibrated at the posterior mode from the estimation of the quantitative model in Section 4, we

[15]It is important to emphasize that, when making this comparison, we disregard model-specific features such as price indexation, which implies that all prices mechanically reset each period. As a result, the model-generated f_t does not correspond to the overall frequency of price changes, but rather reflects the frequency of optimally re-optimized prices.



(a) Responses to a + 0.25% monetary policy shock



(b) Responses to -0.5% cost-push shock

Notes: The parameter used are the posterior mode of the baseline model (see Table 1).

Figure C.2: IRFs as a function of the steady state trend inflation level obtain $\beta_0 = 3.36$ and $\beta_1 = 0.97599$. These figures are close to the L'Huillier and Schoenle's (2024) finding – i.e. $\beta_0 \in [4.61 : 7.42]$ and $\beta_1 \in [0.98 : 2.26]$ – where they regress Nakamura et al. (2018) price setting frequency data against various trend inflation measures for the US.

Figure C.2 relates to the effect of trend inflation on the dynamics of the model, by showing how the IRFs to monetary and cost-push shocks change with the level of trend inflation. The higher the level of trend inflation, the more flexible are wages and prices. Hence, consistent with results in the literature, the more monetary policy shocks affect inflation and the more cost-push shocks affect output.

D State-Dependent IRFs

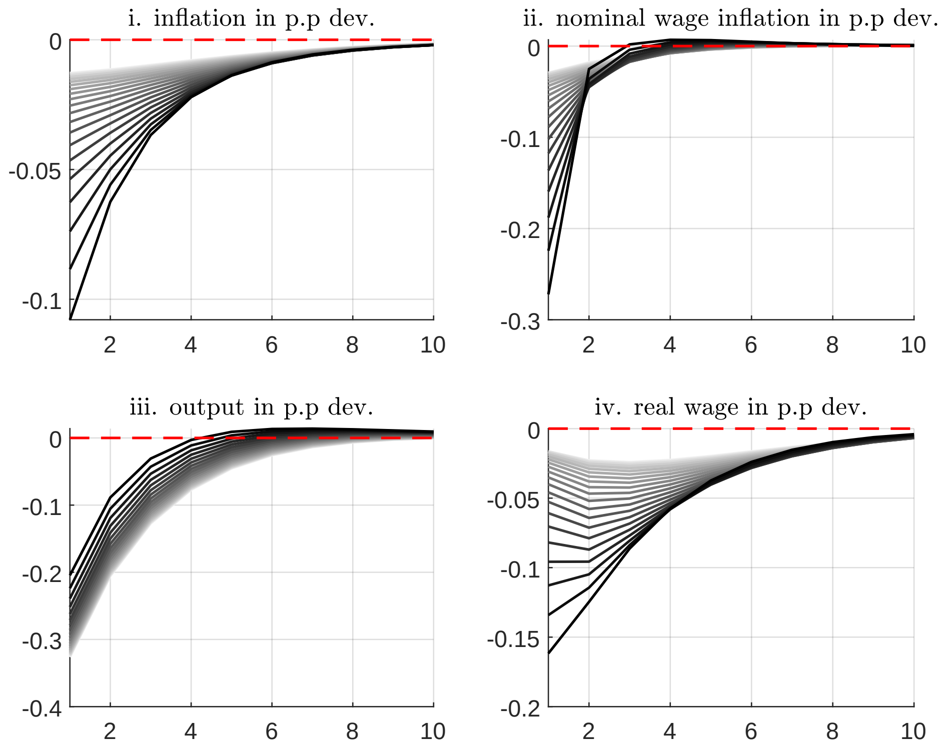
Figure D.1 displays state-dependent impulse response functions (IRFs), computed by simulating a vector of labor supply shocks that generate inflation paths ranging from an initial annualized inflation rate of 0.5% to 5.5%. On top of each initial labor supply shock, we add either an additional $\varepsilon_{r,1} = 0.25\%$ monetary policy shock, as shown in Figure D.1a, or a $\varepsilon_{p,1} = -0.5\%$ cost-push shock, as shown in Figure D.1b. We report all the variables in deviation from the baseline underlying IRFs (i.e. minus the response to the initial labor supply shock).[16] Darker lines indicate higher initial inflation levels, corresponding to more negative underlying cost-push shocks. In a quasi-linear model, such as the standard Calvo model, all shocks would generate quasi-identical dynamics regardless of the initial inflation level, and all lines would overlap. Consequently, there would be no state dependency in the responses.[17] In this model, instead, we observe clear state dependency. For monetary policy, the inflation response is stronger when initial inflation is high. The underlying mechanism can be explained as follows: at higher levels of inflation, the shares of firms and unions not optimally updating the price and wage are lower, meaning that prices and wages are more flexible. This increased flexibility steepens the Phillips curves, amplifying the effects of monetary policy shocks. Thus, the higher the initial level of inflation, the larger the variations in inflation and the smaller the ones in output induced by a given contractionary monetary policy shock.

Moreover, a second-order effect due to the forward-lookingness of firms and unions further affects this state dependency. Firms and unions would anticipate the change in the frequency of price and wage resetting. In other words, they will anticipate if in the future the economy will be on a flatter or a steeper part of the Phillips curves. These effects tend to dampen the inflation response to contractionary monetary policy shocks, because the decline in inflation makes price and wage adjustments less appealing in expectation, and nominal adjustment more rigid downward. However, the opposite occurs for expansionary monetary policy shocks. Since firms (union) anticipate future increases in price (wage) resetting frequencies effectively, they would choose a higher reset price, amplifying the response of inflation. Hence, expansionary monetary policy when initial inflation is high can ignite a strong inflationary dynamics.

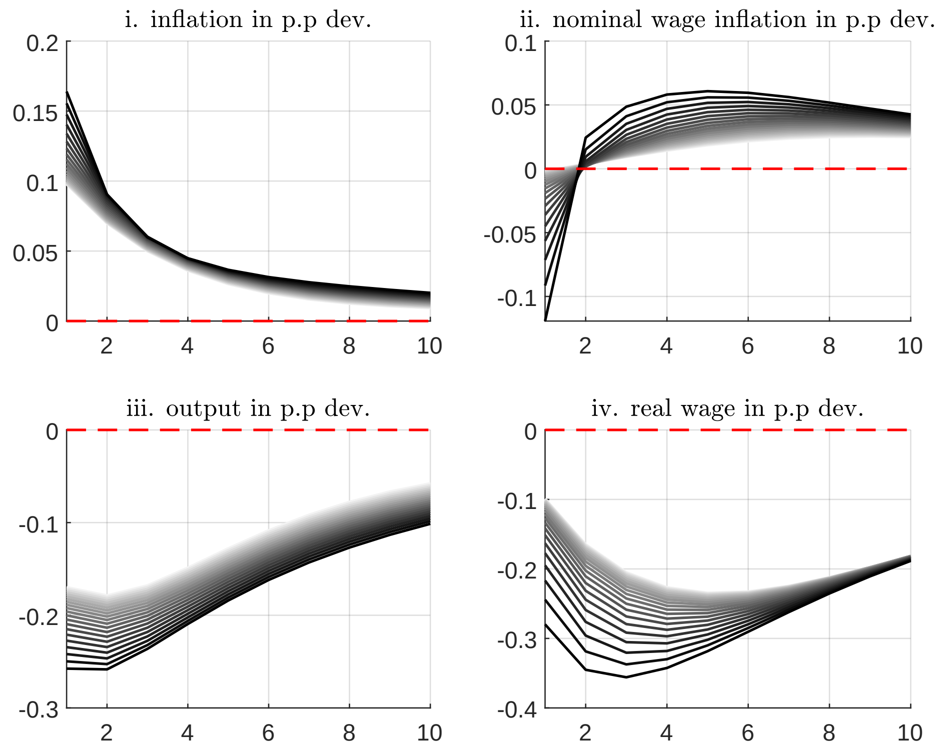
Finally, the relative changes in the steepness of the NKPCs lead to pronounced differences in real wage dynamics. Under conditions of high inflation, both the wage and price NKPCs become substantially steeper. This steepening amplifies the responsiveness of real

[16]We use labor supply and not a cost-push shock because on impact the former moves wage and price inflation in the same direction.

[17]In the Calvo model, most of the difference will be generated by the non-linearity in labor supply FOC and the effect of wages and prices dispersion on marginal cost.



(a) Responses to a + 0.25% monetary policy shock



(b) Responses to -0.5% cost-push shock

Figure D.1: **IRFs are state-dependent.** The lines represent IRFs to a monetary policy (Panel (a)) and a cost-push (Panel (b) shock, for different level of starting inflation. The darker the line, the higher the initial inflation level.

Notes: The initial inflation level are generated by a vector of labor supply shocks of different sizes.

wages to demand shocks, resulting in stronger and more immediate adjustments. For example, when inflation rises, firms and unions adjust nominal wages and prices more frequently and by larger magnitudes, facilitating rapid realignment of real wages to changing economic conditions. However, despite the magnitude of these adjustments, the increased flexibility in the economy – driven by the endogeneity of price and wage setting – ensures that these real wage deviations are less persistent. In other words, while the immediate response of real wages to shocks is stronger in a high-inflation environment, the economy's enhanced adaptability allows it to absorb and dissipate these deviations more quickly.

The mechanism underlying the cost-push shock is similar to that of monetary policy shocks: the economy becomes more flexible when inflation is high, causing supply shocks to have a larger impact both on inflation and on output. A subtle yet important observation is that while these shocks propagate more strongly, they do not exhibit greater persistence. This is because, in a high-inflation environment, shocks travel faster through the economy due to its increased flexibility.

Moreover, a cost-push shock induces an opposite response of price and wage inflation. While firms increase prices, triggering a contraction in demand, which reduces both nominal wage inflation and the desired real wage. This reduction in wage inflation dampens the incentives for unions to reset wages, leading to fewer adjustments on the extensive margin of wage setting. Over time, however, this initial effect gives way to a standard price-to-wage feedback loop, where wages, as inflation remains elevated, become more flexible to catch up with the higher price levels. This adjustment reflects the endogenous response of wage-setting mechanisms to prolonged inflationary pressures, highlighting the interaction between the extensive and intensive margins of price and wage adjustments. It is worth noting that this dynamic interplay in our model makes the required adjustment to a negative supply shock, through lower both real wages and output, very persistent, no matter what the starting inflation level.

E Real time optimal inflation targeting

In Figure E.1, we extend our analysis by considering real-time discretionary inflation targeting. Unlike the exercise described in Section 5, where we looked at the implications of varying the parameters of the Taylor rule, we now consider an optimal targeting exercise. We assume that, in each period t, the central bank's forecast about the economy's future is given by the model's unconditional forecast. Importantly, to circumvent the forward guidance puzzle, we assume that the central bank does not communicate future interest rate paths explicitly so agents form expectations based on the model's estimated Taylor rule. The central bank thus controls the short-term rate through contemporaneous monetary policy shocks - i.e., in deviation from the rule - and, in each period t, selects the shock that minimizes the present value of the expected future loss function.

Since the central bank cannot anticipate future shocks, we implement this approach recursively. That is, at each period, the central bank updates its policy decision based on the prevailing conditions without incorporating knowledge of future exogenous shocks. This ensures that policy is dynamically consistent and remains based on real-time information, rather than relying on perfect foresight.

A key question is why we rely on an add-hoc loss function instead of microfounded conditional welfare measures. Given the current parameterization at the posteriors' modes, households exhibit an extreme aversion to inflation, which leads to counterintuitive results – agents would prefer a unrealistic output contraction rather than tolerate a small overshoot

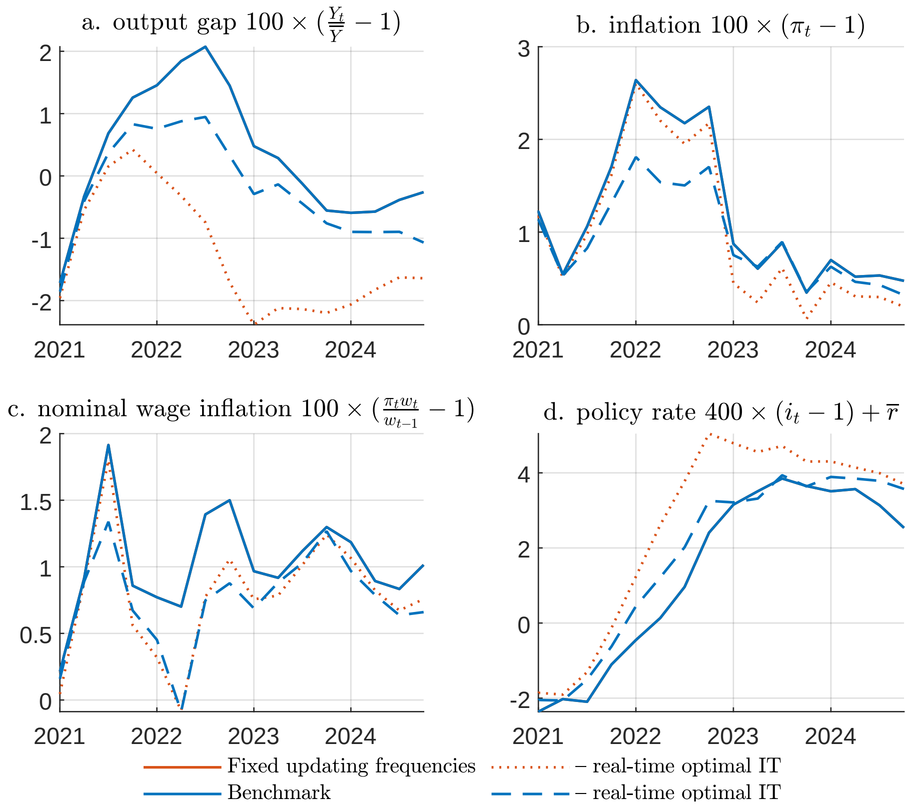


Figure E.1: **Recursive real time inflation targeting under discretion have different prescription and effect.** Counterfactual exercise finding recursively the MP shocks that minimize the CB's loss function in the benchmark and fixed updating frequencies models. Red lines: fixed updating frequencies, blue lines: benchmark model. Dotted and Dashed lines: optimal policies.

Notes: Counterfactual simulations in the benchmark model (blue lines) and the model with fixed adjustment frequencies (red lines) during the 2021q1-2023q4 period. The real time inflation targeting is constructed such that starting in 2021Q1, at each period the Central Bank – through monetary policy shocks – set the policy rate that minimize its expected loss function conditional on the information set available. The loss function reads as $\mathscr{L}_t = \left(100 \times (\pi_t - \overline{\pi})\right)^2 + \left(100 \times (R^4_t - R^4_{t-1})\right)^2 + \beta \mathbb{E}_t \mathscr{L}_{t+1}$.

in inflation. This strong aversion likely stems from the nonlinearities in price and wage dispersion, combined with the quasi-linear disutility of labor in both models alongside very concave utility gain from consumption. Additionally, conditional welfare measures vary significantly across the two different parameterizations of the models, leading to preference structures that are highly model-dependent. Finally, in absence of financial friction, the central bank does take into consideration the policy rate volatility. Therefore, using a consistent add-hoc inflation targeting loss function approach allows for greater comparability across exercises and mitigates model-specific biases in welfare measurement.

Therefore, we set up the Central Bank loss function in such way

$$\mathscr{L}_t = \left(100 \times (\pi_t - \overline{\pi})\right)^2 + \left(100 \times (R^4_t - R^4_{t-1})\right)^2 + \beta \mathbb{E}_t \mathscr{L}_{t+1}$$

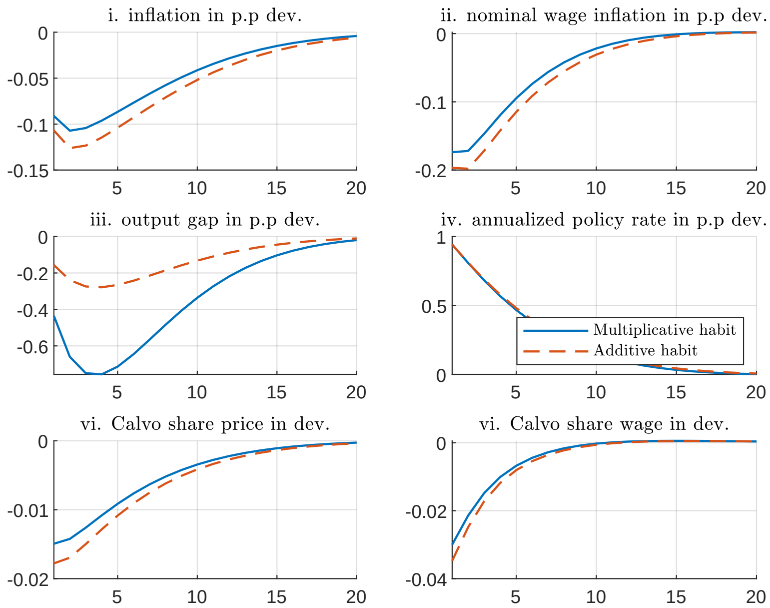
where the central bank minimize the inflation deviation from the target and policy rate volatility as a proxy for financial friction. To be clear, the purpose of this section is not to be a fully-fledged optimal policy exercise, which would be also strongly depend on the implied output gap but to assess the monetary policy stance and maximal output loss given strict inflation targeting objective.

A final caution is warranted when comparing the outcomes of the real-time optimal policy exercises. While both the benchmark and the fixed updating frequency models align with the data in their respective baseline cases, they rely on different structural parameters and shock dynamics. Therefore, the objective of this section is to examine robust optimal policies given model uncertainty. Accordingly, we focus on highlighting the differences in optimal inflation targeting prescriptions across the two models, rather than evaluating the intrinsic performance of these policy recommendations.

Our results highlight key differences in policy responses under alternative price and wage-setting mechanisms. In the fixed-updating frequency model, inflation is initially perceived as slightly above the target and highly persistent (see Figure 5b), primarily driven by near-unit-root cost-push shocks. The stabilization trade-off is significant due to the flat Phillips curve, which limits the sensitivity of inflation to economic slack. As a result, in real-time, the optimal inflation targeting initially implies hard tightening (here depicted by the alternative evolution of the shadow rate in the bottom right panel). This leads to a sharp increase in the real interest rate, generating a substantial decrease in the output gap. Given the muted pass-through from economic activity to inflation even this harsh tightening lead to strong trade-off in economic stabilization and initially little effect on inflation. However, as level and persistence of the policy strange increase, the increase in slack lead to strong disinflationary dynamics starting in 2023.

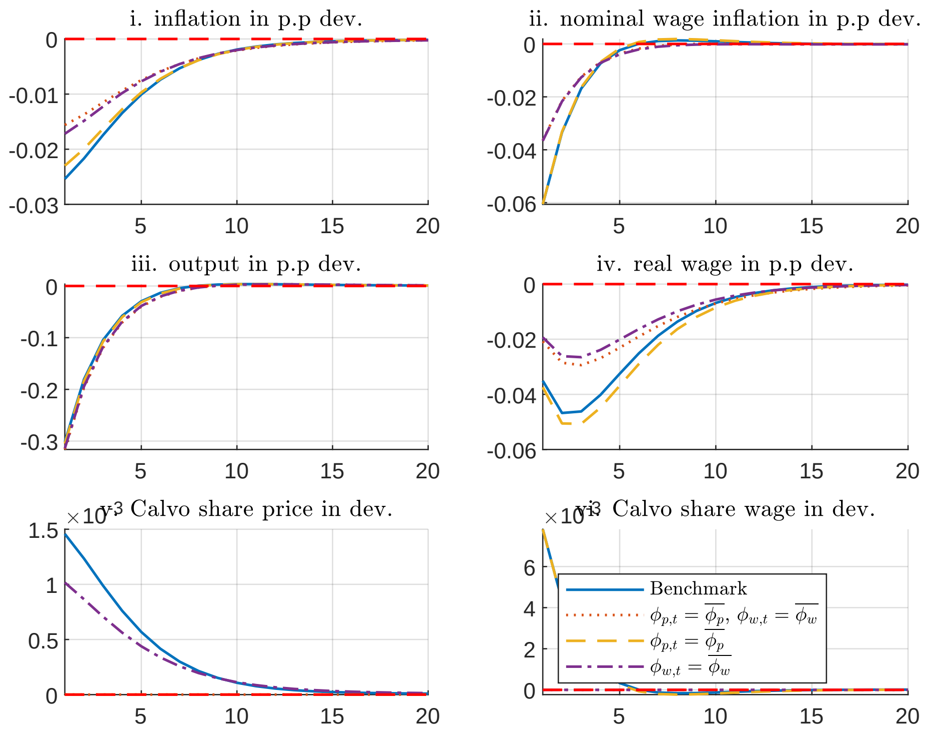
By contrast, in our benchmark model, inflation surprises are perceived as shorter-lived but occur repeatedly. This results in a less aggressive tightening path than in the fixed-updating Calvo model, and slightly more aggressive than, but fairly close to, the realized one. Moreover, the steeper Phillips curve enhances the transmission of monetary policy, leading to far lower inflation and a less pronounced output loss than in the fixed-updating frequency model.

F Additional figures

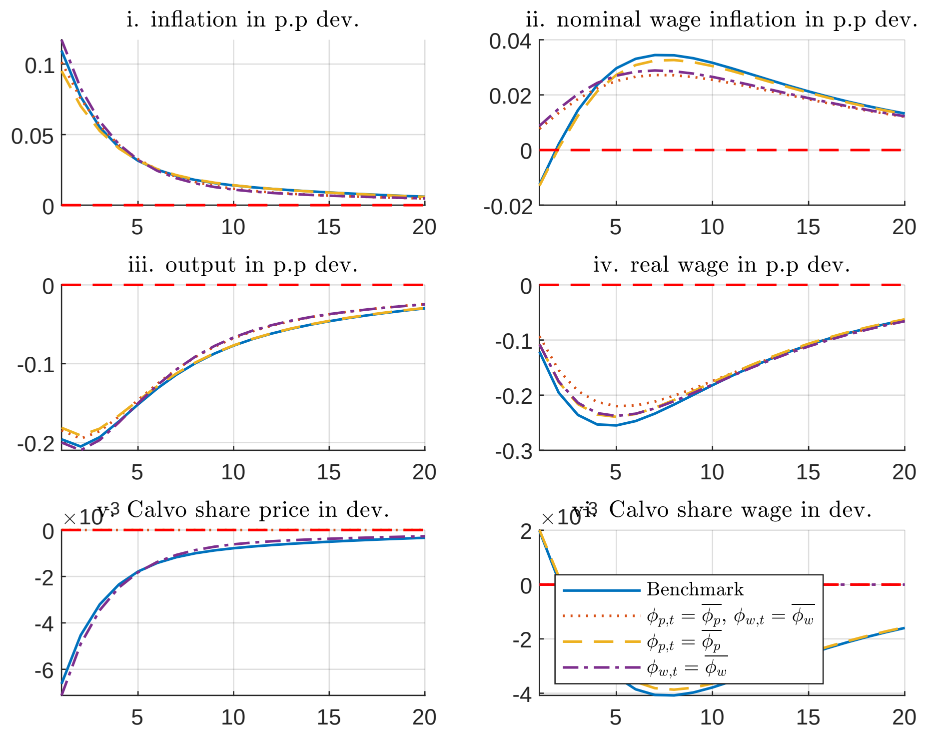


Notes: The parameter used are the posterior mode of the quantitative fixed Calvo model (see Table 1).

Figure F.1: IRFs to a + 0.25% monetary policy shock as a function of the habit formation assumption



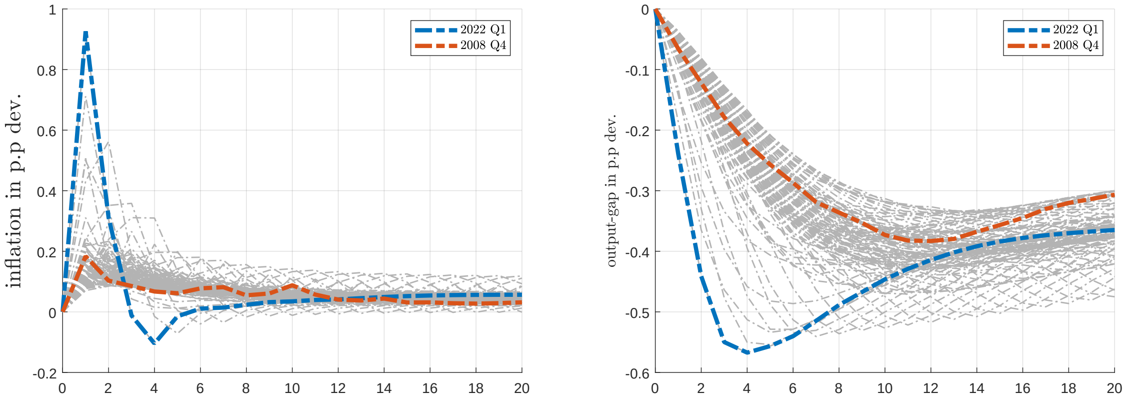
(a) Responses to a + 0.25% monetary policy shock



(b) Responses to -0.5% cost-push shock

Notes: The parameter used are the posterior mode of the baseline model (see Table 1).

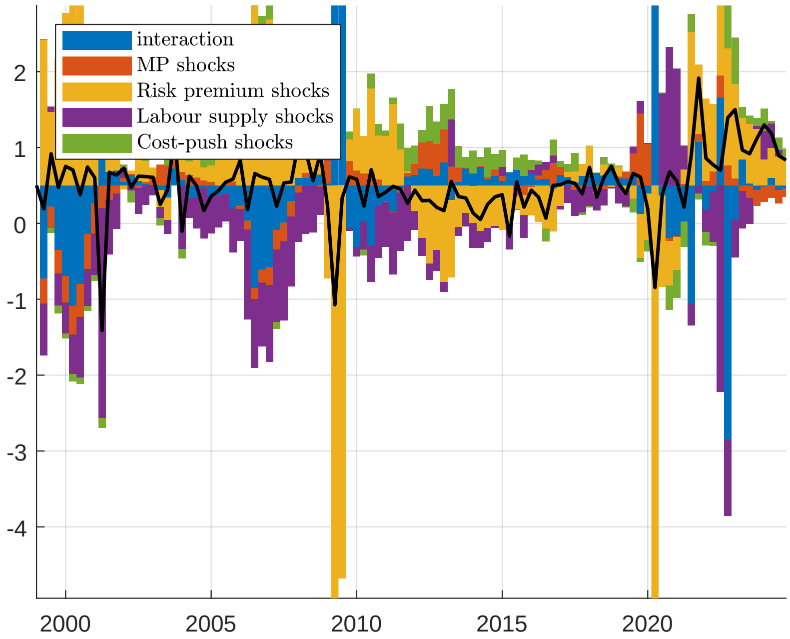
Figure F.2: IRFs with and without state dependency in price and wage setting



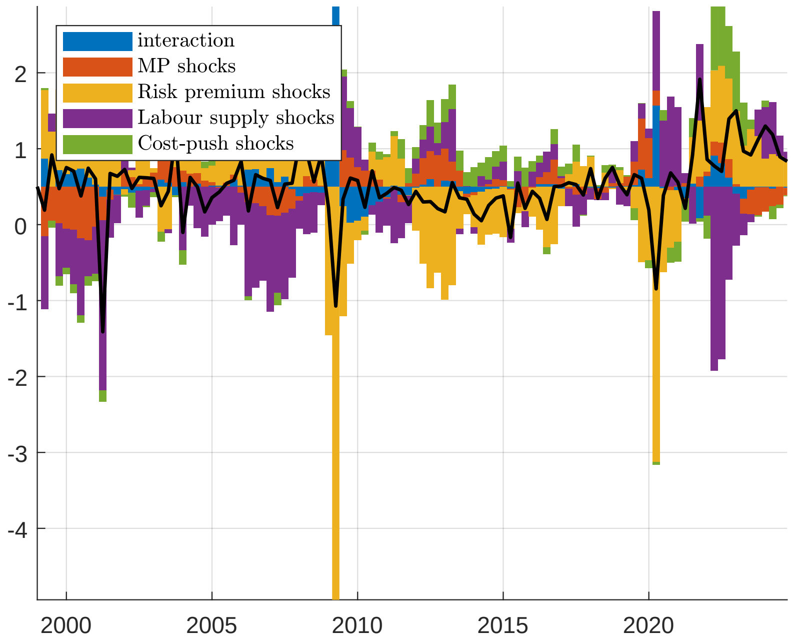
(a) IRFs of inflation

(b) IRFs of output

Figure F.3: **IRFs to an +** 0.5% **cost push shock as function of the state** Panel (a): Inflation. Panel (b): Output. State-dependent IRFs are calculated by comparing the IRFs from all filtered shocks, including an additional contemporaneous cost-push shock, with the IRFs from the same set of shocks without the cost-push shock. This isolates the effect of the cost-push shock conditional on the initial state.



(a) Benchmark



(b) Fixed updating frequency

Notes: See Figure 6.

Figure F.4: Historical decomposition of nominal wage inflation