Inflation Plucking Cycles*

Oskar Juul[a] Peter Lihn Jørgensen[b]

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Abstract

We document that inflation in advanced economies displays "plucking" cycles: Increases in inflation are followed by decreases of similar amplitude, whereas the amplitude of a decrease does not predict the amplitude of the subsequent increase. We provide econometric evidence that monetary policy and supply shocks have asymmetric effects on inflation consistent with the observed plucking-cycle behavior. A nonlinear New Keynesian model with capacity constraints can match our empirical findings. The model gives rise to a convex price Phillips curve, a positive inflation bias, and a negative output gap bias. Optimal monetary policy responds aggressively to large negative supply shocks.

Keywords: Inflation, Plucking cycles, Nonlinear Phillips curve, Optimal monetary policy

JEL classification: E31, E32, E37, E52, E58

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[a]School of Business and Economics, University of Tübingen. Email: oskar.juul@uni-tuebingen.de. Address: Mohlstraße 36, 72074 Tübingen, Germany.

[b]Department of Economics, Copenhagen Business School. Email: pljo.eco@cbs.dk. Address: Porcelænshaven 16 A, 2000 Frederiksberg, Denmark.

1. Introduction

This paper documents a new empirical fact about inflation dynamics in advanced economies: Inflation displays "plucking" cycles, that is, a tendency for inflation to rise temporarily above its long-term trend but rarely drop below it. Figure 1.1 illustrates this property. The figure compares symmetric inflation cycles to plucking cycles. In the former case, inflation fluctuates symmetrically around its long-term trend, as in the workhorse New Keynesian model. In the latter case, inflation behaves like a string attached to a floor that is "plucked" upward by inflationary shocks but rarely pushed below the floor by disinflationary shocks.[1] The plucking property yields the following testable implication: Increases in inflation are followed by decreases of similar amplitude. In contrast, the amplitude of a decrease does not predict the amplitude of the subsequent increase. We provide empirical evidence of this asymmetric pattern for nearly all OECD countries, including the US.

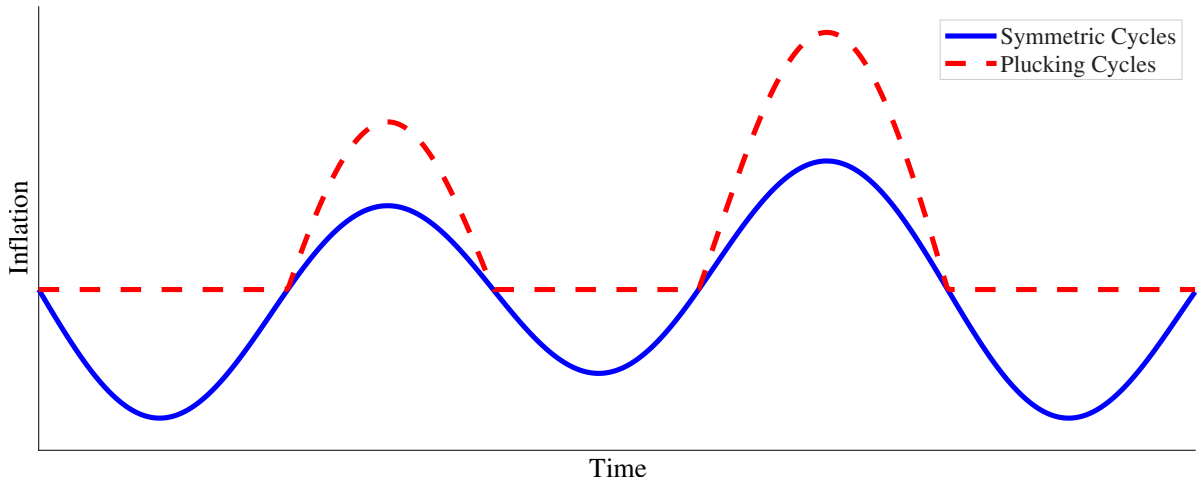


Figure 1.1. Inflation cycles: Symmetric versus plucking.

To uncover the underlying drivers of the inflation plucking cycles, we employ econometric techniques to test for possible asymmetries in the response of inflation to macroeconomic shocks. Specifically, using the Functional Approximations of Impulse Responses (FAIR) method developed by Barnichon and Matthes (2018), we provide empirical evidence on the asymmetric effects of both monetary policy shocks and supply shocks. First, consistent with the results in Barnichon and Matthes (2018), we find that expansionary monetary policy shocks lead to relatively large increases in inflation (but relatively small increases in output), whereas contractionary monetary policy shocks lead to relatively small reductions in inflation (but relatively large reductions in output). Second, we find that negative supply shocks generate relatively large increases in inflation (and relatively large reductions in output), whereas positive

[1] The analogy of a string was first used by Friedman (1964) to describe US business cycle dynamics.

supply shocks generate relatively small reductions in inflation (and relatively small increases in output). Taken together, these findings imply that both monetary policy shocks and supply shocks give rise to right-skewed inflation plucking cycles similar to those we document in the OECD data. Moreover, both types of shocks generate left-skewed plucking cycles in output, consistent with Friedman's (1964; 1993) plucking model and the empirical evidence presented by Dupraz, Nakamura, and Steinsson (2025).

What can explain the asymmetric responses of inflation and output observed in the data? Friedman (1964) argued that output is constrained by a "ceiling of maximum feasible output," reflecting the economy's productive capacity at a point in time. Motivated by this idea, we examine whether capacity constraints, as measured by the energy and industry shortage index developed by Caldara, Iacoviello, and Yu (2026), respond asymmetrically to monetary policy and supply shocks. Consistent with Friedman's hypothesis, we find that an expansionary monetary shock leads to a sharp increase in the shortage measure, indicating a tightening of capacity constraints. In contrast, a contractionary monetary shock has little effect on the shortage measure, which remains essentially flat. Similarly, the shortage measure responds strongly to negative supply shocks, indicating tighter capacity constraints, while displaying a milder response to positive supply shocks.

To account for the empirical evidence, we extend an otherwise standard New Keynesian model with a scarce non-labor input with low substitutability in production. We show that the fully nonlinear version of the model—which we solve with global methods—can match the inflation plucking property. The model also accounts for the asymmetric responses of inflation and output to monetary policy shocks and supply shocks documented in the data.

The key source of nonlinearity in the model is the non-labor production input, which we broadly interpret as energy or specialized capital (e.g., semiconductors). Because the non-labor input is difficult to substitute, a large negative supply shock disproportionately reduces output and raises firms' marginal costs, triggering a surge in inflation. By contrast, a large positive supply shock has only a modest effect on output and generates limited disinflationary pressure, as marginal costs remain nearly constant. Similarly, a large expansionary monetary policy shock pushes the economy against capacity constraints, producing a sharp increase in inflation but only a muted increase in output. Conversely, a contractionary monetary policy shock generates a relatively small decline in inflation but a pronounced contraction in output. These asymmetric responses of marginal costs to both monetary policy and supply shocks generate right-skewed inflation plucking cycles similar to those documented in the data.

The presence of plucking cycles has first-order implications for welfare and mon-

etary policy. In standard linear models, inflation fluctuates symmetrically around the central bank's target rate, while output fluctuates symmetrically around potential output. Stabilization policy does not influence the average levels of these variables, and the associated welfare gains are therefore negligible (Lucas, 1987, 2003). In contrast, in our nonlinear model, inflation *exceeds* the central bank's inflation target on average, and average output falls short of its efficient level. These biases are a byproduct of a convex price Phillips curve: Negative supply shocks and expansionary monetary shocks disproportionally raise inflation, whereas positive supply shocks and contractionary monetary shocks disproportionally reduce the output gap. Due to these biases, the welfare costs of business cycles are significantly higher in the nonlinear model relative to its linearized counterpart.

How should monetary policy respond to supply shocks? To answer this question, we solve the nonlinear Ramsey problem under commitment. We obtain the following results. As is well known from the textbook New Keynesian model with sticky wages, a second-order approximation to household welfare implies that optimal monetary policy faces a trade-off between stabilizing price inflation, wage inflation, and the output gap (Galí, 2015). In our nonlinear model, large negative supply shocks disproportionally raise inflation, leading the real wage to drop substantially below its natural level. This initial reduction in the real wage is followed by a long-lasting period of costly nominal wage adjustment. As a result, negative supply shocks generate relatively large welfare losses. We show that optimal monetary policy responds aggressively to large negative supply shocks. By utilizing the convexity of the price Phillips curve, the central bank can facilitate a large disinflation without significantly reducing the output gap.

Large positive supply shocks, on the other hand, lead to relatively muted responses of both price and wage inflation. Moreover, they generate an unfavorable trade-off for the Ramsey planner: On the flat part of the Phillips curve, stabilizing inflation can only be achieved by pushing output substantially above its natural level. As a result, the Ramsey planner responds less aggressively to large positive supply shocks.

The Ramsey planner's asymmetric response to positive versus negative supply shocks serves to almost fully correct the inflation and output gap biases that arise when the central bank follows a standard Taylor rule. By responding more aggressively to large negative supply shocks, the Ramsey planner can reduce the average rate of inflation and raise the average level of output, yielding substantial welfare gains. By construction, these level effects are absent in linear models.

Related literature. The concept of "plucking cycles" was introduced by Friedman (1964, 1993) to describe US business cycle dynamics. According to Friedman, output frequently drops below its longer-term trend but rarely rises above it. Business cycles

should therefore be viewed as "plucks" below the economy's full potential ceiling, rather than symmetric fluctuations around its long-run trend. As Friedman (1964) noted, a testable implication of the plucking model for output is that the size of a recession predicts the size of the subsequent expansion, while the size of an expansion does not predict the size of the subsequent recession. In a recent paper, Dupraz, Nakamura, and Steinsson (2025) provide strong empirical evidence that the behavior of the US unemployment rate is consistent with this pattern.[2] To the best of our knowledge, our paper is the first to extend the concept of "plucking" to inflation dynamics.

Post-pandemic inflation has spurred a large body of literature on nonlinearities in the Phillips curve relationship (e.g., Harding, Lindé, and Trabandt, 2023, Benigno and Eggertsson, 2024, Blanco et al., 2024, Cerrato and Gitti, 2025). The original contribution of Phillips (1958) and, more recently, Boehm and Pandalai-Nayar (2022) and Bunn et al. (2025) provide empirical evidence in favor of a convex Phillips curve, as implied by our model.[3] Closely related to our work is Comin, Johnson, and Jones (2023), who study a model with occasionally binding capacity constraints, which gives rise to a similar nonlinearity in the price Phillips curve. Our model resembles those of Lorenzoni and Werning (2023) and Gagliardone and Gertler (2026) but with the key difference that we study the nonlinear version of the model. In this respect, our work is related to Baqaee and Farhi (2019), who show that nonlinearities in multi-sector models can cause shocks to critical sectors to have disproportionate effects on aggregate output.[4]

Karadi et al. (2024) also study optimal monetary policy in a model with a nonlinear Phillips curve. The source of nonlinearity in their model is the state-dependent price-setting of Golosov and Lucas (2007). Closer to our paper is De Polis, Melosi, and Petrella (2024) who study optimal monetary policy in a linearized model with perceived skewness in the distribution of markup shocks. Similar to our paper, these authors find that optimal monetary policy should account for asymmetric inflation risk.

Roadmap. The rest of the paper is organized as follows. Section 2 contains empirical evidence on inflation plucking cycles in the OECD countries as well as econometric ev-

[2]More recently, Boeck, Grimaud, and Zanetti (2026) link the plucking property of unemployment to the Phillips curve through nonlinearities associated with labor-market tightness. The remaining literature on Friedman's plucking theory is relatively scarce. Kim and Nelson (1999) and Sinclair (2010) use econometric models to test Friedman's plucking theory. Hartley (2021) and Kohlscheen, Moessner, and Rees (2024) present cross-country evidence of plucking cycles in output and unemployment, respectively.

[3]Along similar lines, Babb and Detmeister (2017) find that the slope of the Phillips curve at the US metropolitan-level steepens at low levels of unemployment, while Forbes, Gagnon, and Collins (2022) provide cross-country evidence that the Phillips curve flattens at low levels of inflation.

[4]Our paper is also related to the growing empirical literature documenting nonlinear responses of macroeconomic variables to shocks (e.g., Auerbach and Gorodnichenko, 2012, Tenreyro and Thwaites, 2016, Barnichon, Debortoli, and Matthes, 2022, Debortoli et al., 2025).

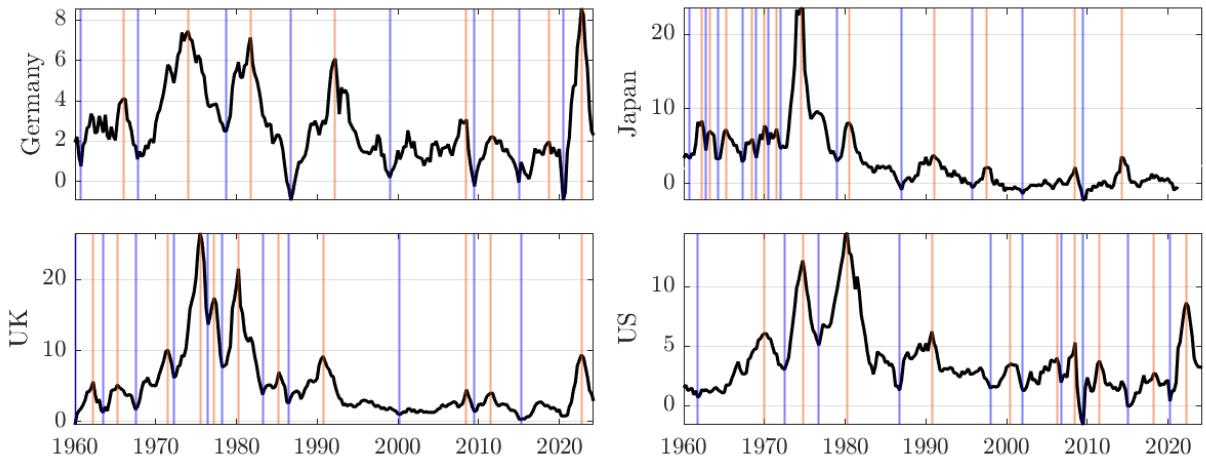


Figure 2.1. Inflation peaks and troughs. This figure displays quarterly data on inflation from 1960Q1 to 2024Q2, along with marked peaks of inflation (red) and troughs (blue) for Germany, Japan, the United Kingdom, and the United States.

idence on the asymmetric responses of inflation to macroeconomic shocks. In Section 3, we set up a New Keynesian model with a scarce non-labor production input with low substitutability in production. In Section 4, we show that the model, when solved with global methods, can generate inflation plucking cycles and asymmetric responses to shocks, similar to those we document in the data. In Section 5, we investigate the implications for welfare and optimal monetary policy. Section 6 concludes.

2. Empirical evidence

2.1 Inflation plucking cycles

In this section, we show that inflation rates in the US and most other OECD countries display plucking cycles. We start by collecting quarterly data on CPI inflation for all 38 OECD countries. For most countries, these data are available for the period from 1960Q1 to 2024Q2 (for details, see Appendix A.1). As a baseline, we exclude "extreme" observations from our dataset, which we define as inflation cycles where annual inflation exceeds 50 percent. In these cases, we start the country-specific sample on the date of the subsequent inflation trough, excluding all prior observations.[5]

Next, we identify inflation peaks and troughs in the data using the algorithm developed by Dupraz, Nakamura, and Steinsson (2025). The algorithm identifies peaks and troughs in the data, conditional on a threshold parameter that specifies the minimum absolute distance between them. We set this parameter to 2 percent, implying that inflation must increase by at least 2 percentage points from the previous trough to

[5]This restriction excludes around 5 percent of our observations.

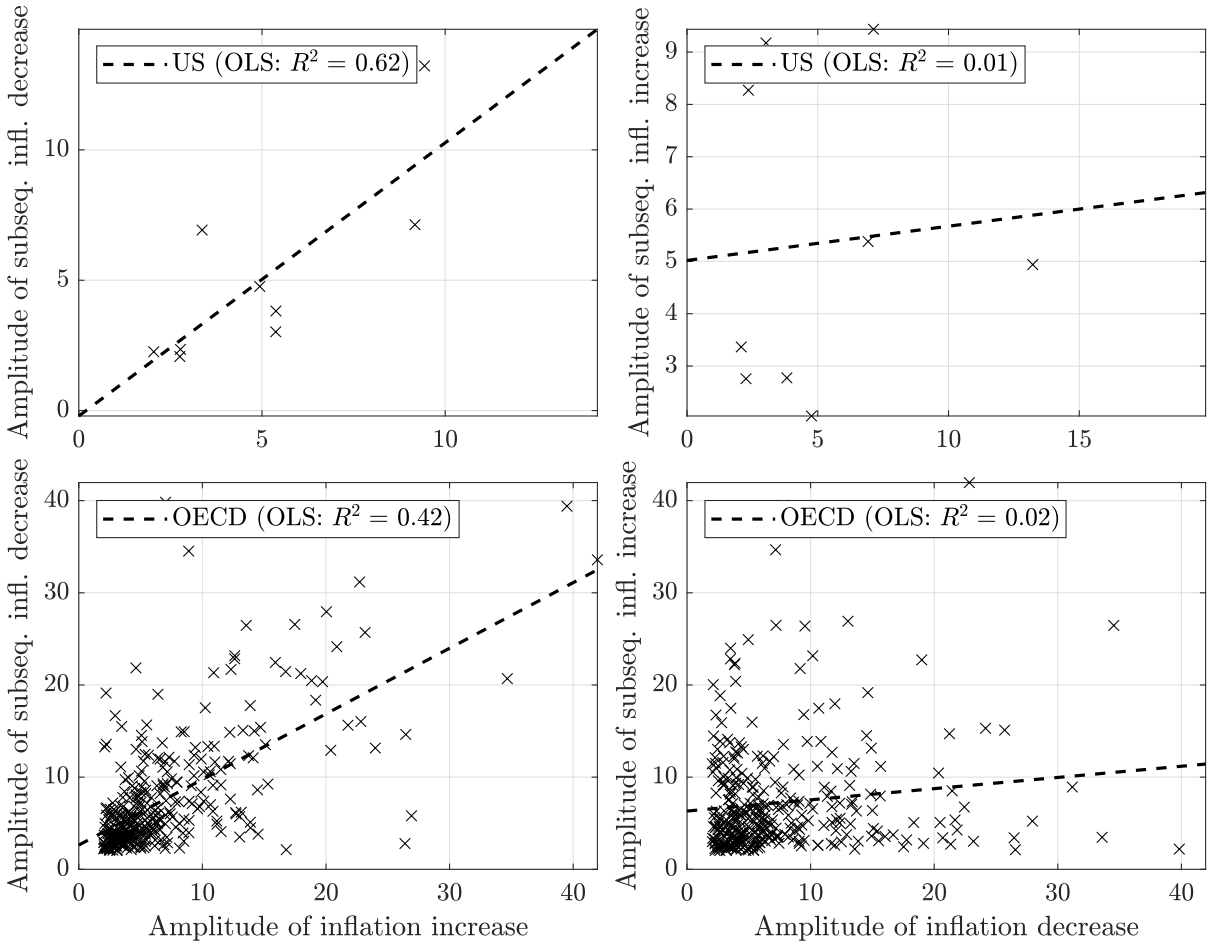


Figure 2.2. Inflation plucking cycles. This figure displays scatter plots of amplitudes of inflation cycles in US data (upper panels) and cross-country pooled OECD data (lower panels). The dashed lines are univariate OLS regression lines. The left panels show amplitudes of inflation increases versus subsequent inflation decreases. The right panels show amplitudes of inflation decreases versus subsequent increases.

be considered a peak, or decrease by at least the same amount from the previous peak to be considered a trough.[6]

Figure 2.1 shows CPI inflation rates from four OECD countries (Germany, Japan, the United Kingdom, and the United States), where blue vertical lines mark inflation troughs, and red vertical lines mark inflation peaks. Using the identified peaks and troughs, we compute the amplitude of an increase in inflation as the difference between the peak value and the previous trough value. Similarly, we compute the amplitude of a decrease in inflation as the (absolute) difference between the trough value and the previous peak value.

Figure 2.2 illustrates the key property of inflation plucking cycles. The upper left panel contains a scatter plot of the amplitudes of observed increases in US inflation against the amplitudes of subsequent reductions. The dashed line is a univariate OLS regression line. The statistical relationship is significant at the 1 percent level with an

[6]Our findings are robust to alternative values of this parameter.

	United States		Cross-country OECD	
Regressor:	Increase	Decrease	Increase	Decrease
Regressand:	Subseq. decrease	Subseq. increase	Subseq. decrease	Subseq. increase
$\hat{\beta}_1$	1.05^{***} (0.27)	0.07 (0.27)	0.71^{***} (0.05)	0.12^{***} (0.05)
R^2	0.62	0.01	0.42	0.02
n	9	9	346	341

Table 2.1. Plucking property of inflation. This table reports OLS regression results. The asterisk *** denotes significance at the 1 percent level.

R^2 of 0.62. As the figure shows, there is roughly a one-for-one relationship between the amplitude of an increase in US inflation and the amplitude of the subsequent reduction. In contrast, the upper right panel in Figure 2.2 shows no statistically significant relationship between reductions in US inflation and subsequent increases.

Similarly, the lower left panel in Figure 2.2 shows the amplitude of observed inflation increases in OECD countries versus subsequent reductions. As for the US, there is a strong positive relationship between increases in inflation and subsequent reductions. The relationship is significant at the 1 percent level with an R^2 of 0.42. Conversely, the lower right panel shows that the statistical relationship between decreases in inflation and subsequent increases is very weak. While the regression coefficient is statistically significant, it is small, and the R^2 of the regression is close to zero.[7] The regression results are summarized in Table 2.1.

Country-specific regressions reveal broad homogeneity across OECD countries, with 33 out of 38 countries exhibiting the plucking property.[8] The country-specific results are shown in Tables A.2 and A.3 in Appendix A. In these regressions, we use all available data. It is worth noting that inflation rates in countries with very different inflation histories—such as Germany and Turkey—display the same plucking property.

Movements in "trend inflation" may blur the plucking property in the data. We therefore conduct two robustness checks of our baseline empirical findings. First, in Section A.3 in Appendix A, we show that our empirical findings are robust if we only consider "low-inflation regimes," which we conservatively define as countries where inflation has not exceeded 10 percent within the sample. Specifically, if inflation exceeds this upper limit, we start the country-specific sample on the date of the subsequent inflation trough, ignoring all prior observations. Second, Section A.4 in Appendix A shows that our findings are robust if we de-trend our inflation data using

[7] The regression coefficient is statistically significant because the number of observations is sufficiently large to detect mean-reversion. We obtain a very similar result in our theoretical model, see Table 4.1.

[8] The five exceptions are Australia, Canada, France, Ireland, and South Korea.

the Hamilton (2017) filter.

2.2 Asymmetric effects of shocks

In this section, we provide econometric evidence that both monetary policy shocks and supply shocks have asymmetric effects on inflation that are consistent with the right-skewed plucking-cycle behavior documented in the previous section. For this purpose, we rely on the econometric technique, Functional Approximations of Impulse Responses (FAIR), which was developed by Barnichon and Matthes (2018) to identify the (possibly) nonlinear dynamic effects of structural shocks. In the following section, we briefly outline the FAIR estimation procedure and present the empirical results. For a comprehensive treatment of FAIR estimation, see Barnichon and Matthes (2018).

2.2.1 FAIR estimation

A key challenge in empirical macroeconomics is how to identify nonlinear dynamic responses to shocks. By construction, standard Structural Vector Autoregressions (SVARs) cannot capture nonlinear effects of shocks, as these models are linear. Local Projections (Jorda, 2005), on the other hand, can easily accommodate nonlinearities, but the flexibility of Local Projections comes at an efficiency cost (Ramey, 2012). The basic idea behind FAIR estimation is to approximate impulse response functions using Gaussian basis functions. Jorda (2023) finds that this dimension-reducing tool can generate considerable efficiency gains while preserving much of the flexibility offered by Local Projections.

Consider the structural vector moving-average (VMA) model

$$\mathbf{y}_t = \sum_{h=0}^{H} \boldsymbol{\psi}_h \boldsymbol{\varepsilon}_{t-h}, \tag{2.1}$$

where $\mathbf{y}_t$ is a $(k \times 1)$ vector of stationary variables, $\boldsymbol{\psi}_h$ is the matrix of lag coefficients, $\boldsymbol{\varepsilon}_t$ is a vector of *iid* structural innovations, and H is the number of lags.

The matrix $\boldsymbol{\psi}_h$ in equation (2.1) contains the impulse responses of $\mathbf{y}_t$ at horizon h to the shocks $\boldsymbol{\varepsilon}_t$ and is a very large (possibly infinite) dimensional object. The idea behind FAIR estimation is to approximate each element of $\boldsymbol{\psi}_h$, denoted by ψ_h, as a sum of Gaussian basis functions:

$$\psi(h) = \sum_{n=1}^{N} a_n \, e^{-\left(\frac{h-b_n}{c_n}\right)^2}, \quad \forall h \geq 0, \tag{2.2}$$

where N is the number of basis functions, and a_n, b_n, and c_n are parameters to be es-

timated. Each of these parameters captures a specific feature of the impulse response, namely the magnitude of the peak effect of a shock, the timing of that peak effect, and the persistence of that peak effect, respectively.

Following Barnichon and Matthes (2018), we allow for asymmetries by estimating a modified version of equation (2.1), where the matrix of impulse responses $\boldsymbol{\psi}_h$ depends on the sign of the structural shocks:

$$\mathbf{y}_t = \sum_{h=0}^{H} \left[\boldsymbol{\psi}_h^+ \left(\boldsymbol{\varepsilon}_{t-h} \odot \mathbf{1}_{\boldsymbol{\varepsilon}_{t-h}>0} \right) + \boldsymbol{\psi}_h^- \left(\boldsymbol{\varepsilon}_{t-h} \odot \mathbf{1}_{\boldsymbol{\varepsilon}_{t-h}<0} \right) \right], \tag{2.3}$$

where $\boldsymbol{\psi}_h^+$ and $\boldsymbol{\psi}_h^-$ are lag matrices of coefficients for, respectively, positive and negative shocks, and $\odot$ denotes element-wise multiplication. In this case, each element of $\boldsymbol{\psi}_h^+$, denoted $\psi^+(h)$, can be approximated by

$$\psi^+(h) = \sum_{n=1}^{N} a_n^+ \, e^{-\left(\frac{h-b_n^+}{c_n^+}\right)^2}, \quad \forall h \in (0, H], \tag{2.4}$$

where a_n^+, b_n^+ and c_n^+ are parameters to be estimated. A corresponding expression holds for $\boldsymbol{\psi}_h^-$.

2.2.2 Data and identification

We estimate a four-variable model on US data covering the period from 1960Q1 to 2024Q2. The model includes (log) real GDP, CPI inflation, the nominal interest rate, and a measure of capacity constraints. For the interest rate, we use data on the federal funds rate over the period 1960Q1-1976Q2 and the "proxy federal funds rate" constructed by Choi et al. (2022) for the remainder of the sample 1976Q3-2024Q2. The proxy federal funds rate captures the broader stance of monetary policy, mitigating the limitations imposed by the zero lower bound.[9] For capacity constraints, we use the energy and industry shortage index developed by Caldara, Iacoviello, and Yu (2026).[10] The index is constructed from US newspaper articles mentioning shortages (e.g., bottlenecks, scarcity) of energy and industrial inputs, which we broadly interpret as a measure of input scarcity.[11]

We use sign restrictions to identify the structural shocks (Uhlig, 2005). For monetary policy shocks, we assume that a contractionary monetary policy shock is the

[9] Barnichon and Matthes (2018) obtain similar results for monetary policy shocks using a sample that ends in 2007Q4, before the onset of the first ZLB episode.

[10] We focus on the combined energy and industry shortage measures from Caldara, Iacoviello, and Yu (2026), as these series exhibit stronger comovement with US inflation over our sample period than the corresponding labor and food shortage measures.

[11] This interpretation differs slightly from that of Caldara, Iacoviello, and Yu (2026), who interpret shortages as reflecting non-market-clearing frictions.

only shock that raises the interest rate but lowers both output and inflation, while the response of shortages is left unrestricted. For supply shocks, we assume that a negative supply shock is the only shock that lowers output but raises inflation, leaving the responses of the interest rate and shortages unrestricted.

Following Barnichon and Matthes (2018), we use the approximation (2.4) for $h > 0$. We impose the sign restrictions on the contemporaneous impact matrices $\boldsymbol{\psi}_0^+$ and $\boldsymbol{\psi}_0^-$ and on the impulse responses, using one Gaussian basis function per impulse response. We estimate the model with Bayesian methods, using a Metropolis-Hastings algorithm to approximate the posterior distribution. For additional details on our estimation, see Appendix A.5.

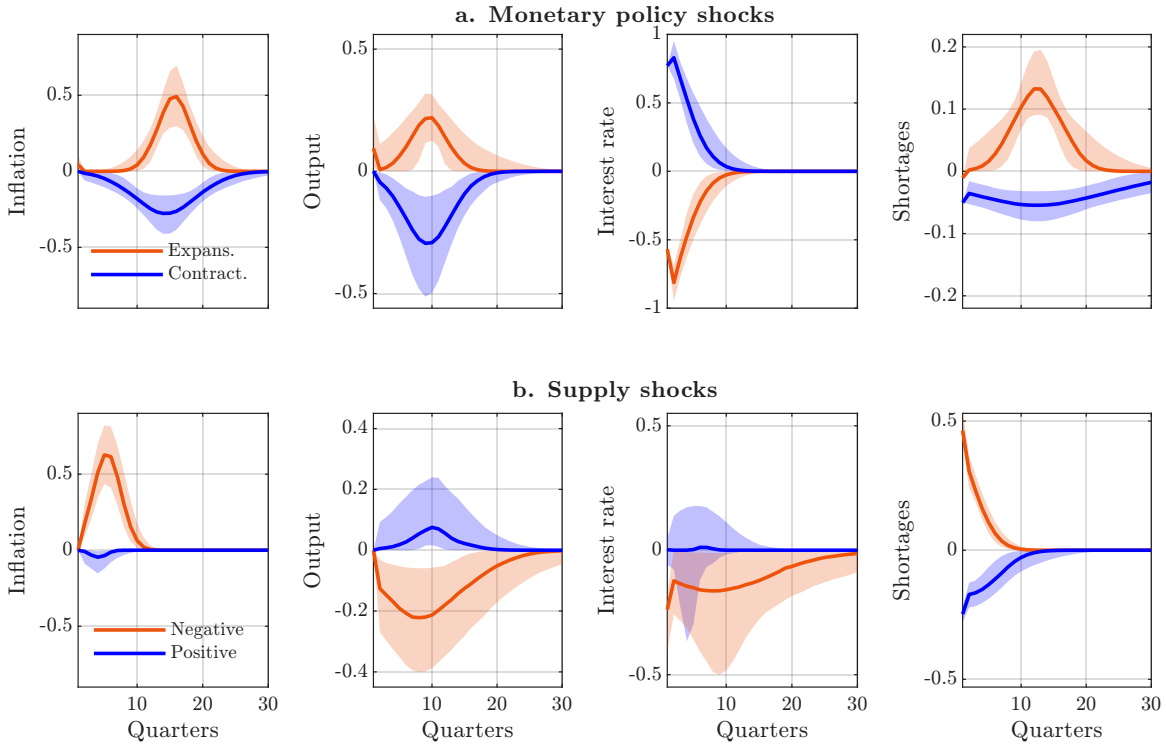


Figure 2.3. Impulse responses. This figure contains impulse responses to one-standard-deviation expansionary versus contractionary monetary policy shocks and positive versus negative supply shocks in US data. Shaded bands denote the 5th and 95th posterior percentiles. Estimation using data covering 1960Q1-2024Q2.

2.2.3 Results

Figure 2.3 displays our econometric results. The upper panels contain the impulse responses to contractionary versus expansionary monetary policy shocks, and the lower panels show the impulse responses to positive versus negative supply shocks.

First, an expansionary monetary policy shock generates a stronger inflation response than a contractionary monetary shock. Conversely, a contractionary monetary shock generates a stronger output response than an expansionary monetary shock.

These findings are consistent with those of Barnichon and Matthes (2018). Second, a negative supply shock generates a stronger response of *both* inflation and output than a positive supply shock. Specifically, a negative supply shock generates a sharp increase in inflation, while a positive supply shock generates a muted inflation response. Similarly, output displays a relatively large decline in response to a negative supply shock but no credible response to a positive supply shock.[12]

Taken together, the results in Figure 2.3 imply that both monetary policy shocks and supply shocks give rise to right-skewed plucking cycles in inflation, consistent with the empirical evidence provided in the previous section. Moreover, both types of shocks generate left-skewed plucking cycles in output, consistent with Friedman's plucking model and the empirical evidence in Dupraz, Nakamura, and Steinsson (2025).[13]

What can explain the asymmetric responses of inflation and output documented in Figure 2.3? The rightmost panels in Figure 2.3 show the responses of the energy and industry shortage measure of Caldara, Iacoviello, and Yu (2026). First, the upper rightmost panel shows that an expansionary monetary shock leads to a sharp increase in the shortage measure, indicating a tightening of capacity constraints. In contrast, a contractionary monetary shock has little effect on the shortage measure, which remains essentially flat.[14] Similarly, the bottom rightmost panel shows that the shortage measure responds strongly to a negative supply shock, indicating tighter capacity constraints, while displaying a milder response to a positive supply shock. Motivated by this evidence, the following section proposes a structural model with capacity constraints that can account for our empirical findings.

3. A New Keynesian model

This section extends an otherwise standard New Keynesian model with a scarce non-labor input with low substitutability in production. The model retains all the standard features of the canonical New Keynesian framework while remaining deliberately simple, allowing us to solve it using global methods. In the model, a continuum of households, each supplying a differentiated labor service, maximize their lifetime

[12] We have verified that the 90 percent posterior credible intervals for the differences between the inflation responses to positive and negative shocks exclude zero for both monetary policy and supply shocks. For output, the corresponding credible intervals exclude zero for supply shocks, but not for monetary policy shocks. Consistent with this finding, our theoretical model generates only modest asymmetry in the output responses to expansionary versus contractionary monetary policy shocks (see Figure 4.2).

[13] We have verified that our results are robust to using the unemployment rate as a measure of economic activity, as in Dupraz, Nakamura, and Steinsson (2025). We focus on GDP because it has a direct counterpart in our New Keynesian model.

[14] Balleer and Noeller (2024) provide microeconometric evidence that supply-constrained firms increase prices more often than unconstrained firms in response to expansionary monetary policy shocks.

utility, and set wages subject to wage adjustment costs. A representative final goods producer aggregates a continuum of intermediate goods into a final good that households consume. Intermediate goods producers operate under monopolistic competition with a constant elasticity of substitution (CES) production function. These firms set prices subject to quadratic price adjustment costs and use labor and a non-labor input in production. Households own a stochastic endowment of the non-labor production input, which they sell to intermediate goods producers on a competitive market.

3.1 Households

A continuum of households of measure one, $j \in [0,1]$, exists. These households aim to maximize their lifetime utility:

$$\mathbb{E}_t \left[\sum_{k=0}^{\infty} \beta^k \left\{ \frac{C_{jt+k}^{1-\gamma}}{1-\gamma} - \frac{L_{jt+k}^{1+\varphi}}{1+\varphi} \right\} \right], \tag{3.1}$$

where $\mathbb{E}_t$ is the expectation operator at time t, $\beta \in (0,1)$ is the subjective discount factor, γ is the coefficient of relative risk aversion, and φ is the inverse Frisch elasticity of labor supply.

The households maximize (3.1) subject to their per-period real budget constraint

$$C_{jt} + b_{jt-1}\left(1+i_{t-1}\right)/\Pi_t = (1+\tau_W) w_{jt} L_{jt} + b_{jt} + d_{jt} - T_{jt} - \Upsilon_{jt}^W, \tag{3.2}$$

where b_t is one-period risk-free real bonds, $(1+i_t)/\Pi_{t+1}$ is the gross real interest rate, w_{jt} is the real wage, τ_W is a labor income subsidy, and T_{jt} is a lump-sum tax. The term, d_{jt}, represents the household's equal share of both the real profits earned by firms and the value of the endowment of the non-labor production input.

An employment agency aggregates households' differentiated labor according to the intermediate firms' demand as in Erceg, Henderson, and Levin (2000). The demand for the j-th household's labor is given by

$$L_{jt} = \left(\frac{w_{jt}}{w_t} \right)^{-\varepsilon_W} L_t,$$

where ε_W denotes the elasticity of substitution between different types of labor.

Households set wages subject to quadratic adjustment costs, which are given by

$$\Upsilon_{jt}^W = \frac{\gamma_W}{2} \left(\Pi_t^W - 1 \right)^2 Y_t,$$

where Π_t^W is the (gross) wage inflation rate, which is linked to the real wage as $\Pi_t^W =$

$\Pi_t w_t / w_{t-1}$.

Solving the maximization problem yields two optimality conditions (after imposing symmetry): An Euler equation for consumption and a wage Phillips curve,

$$1 = \beta \mathbb{E}_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-\gamma} \frac{1 + i_t}{\Pi_{t+1}} \right], \tag{3.3}$$

$$\begin{aligned} (\Pi_t^W - 1)\,\Pi_t^W = \frac{1}{\gamma_W\, Y_t} \Big[\varepsilon_W\, C_t^{\gamma}\, L_t^{\varphi+1} - (1 + \tau_W)(\varepsilon_W - 1)\, L_t\, w_t \Big] \\ + \beta\, \mathbb{E}_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-\gamma} \frac{Y_{t+1}}{Y_t} (\Pi_{t+1}^W - 1)\, \Pi_{t+1}^W \right]. \end{aligned} \tag{3.4}$$

Details on the derivations are in Appendix B.1.1.

The households' stochastic endowment of the non-labor input follows an AR(1) process, as given by

$$X_t = (1 - \rho_X)\, \mu_X + \rho_X X_{t-1} + \varepsilon_t^X, \qquad \varepsilon_t^X \sim \mathcal{N}(0, \sigma_X^2). \tag{3.5}$$

The linear formulation (3.5) ensures—unlike the log formulation—that the variance σ_X^2 does not impact the mean of X_t through Jensen's inequality (Basu and Bundick, 2017).[15]

3.2 Production

A representative final goods producer bundles a continuum of intermediate goods, $i \in [0, 1]$, into a final good that households consume. The demand of the final goods producer for the i-th intermediate good is given by

$$Y_{it} = (P_{it} / P_t)^{-\varepsilon}\, Y_t. \tag{3.6}$$

Intermediate goods firms, operating under monopolistic competition, use the following constant elasticity of substitution (CES) production technology,

$$Y_{it} = \left(\alpha L_{it}^{\frac{\phi-1}{\phi}} + (1 - \alpha)\, X_{it}^{\frac{\phi-1}{\phi}} \right)^{\frac{\phi}{\phi-1}}, \tag{3.7}$$

where α is a share parameter, and $\phi \in (0, \infty)$ is the elasticity of substitution between labor and the non-labor input. For $\phi \to 0$, the inputs are perfect complements and equation (3.7) converges to a Leontief production function. For $\phi \to 1$, we obtain a

[15] The discretization of the shock process in the solution method ensures that X_t is always positive.

Cobb-Douglas production function, and for $\phi \to \infty$, a linear production function with perfect substitutability.

Cost minimization yields the factor demands,

$$L_{it} = \left[\frac{w_t}{\alpha mc_{it}}\right]^{-\phi} Y_{it}, \tag{3.8}$$

$$X_{it} = \left[\frac{p_t^X}{(1-\alpha)\, mc_{it}}\right]^{-\phi} Y_{it}, \tag{3.9}$$

where p_t^X is the relative price of the non-labor input, and mc_{it} is the marginal cost of production.

The objective of the intermediate firm i is to set its prices $\{P_{it+k}\}_{k=0}^{\infty}$ to maximize an infinite horizon of discounted profits:

$$\max_{\{P_{it+k}\}_{k=0}^{\infty}} \mathbb{E}_t \sum_{k=0}^{\infty} q_{t,t+k} m_{it+k}, \tag{3.10}$$

where $q_{t,t+k} = \beta^k \left(C_{t+k}/C_t\right)^{-\gamma}$ is households' stochastic discount factor. Intermediate firms maximize (3.10) subject to the final goods producer's demand (3.6), facing Rotemberg (1982) price adjustment costs:

$$\Upsilon_{it}^P = \frac{\gamma_P}{2}\left(\frac{P_{it}}{P_{it-1}} - 1\right)^2 Y_t. \tag{3.11}$$

The firm's profit equals $m_{it} = (1+\tau_P)\left(P_{it}/P_t\right) Y_{it} - mc_{it} Y_{it} - \Upsilon_{it}^P\left(P_{it}, P_{it-1}\right)$, where τ_P is a government output subsidy. The symmetric equilibrium yields the following price Phillips curve:

$$\left(\Pi_t - 1\right)\Pi_t = \frac{1}{\gamma_P}\left(\left(1+\tau_P\right)\left(1-\varepsilon\right) + \varepsilon mc_t\right) + \mathbb{E}_t\left[\frac{q_{t,t+1}}{q_{t,t}}\left(\Pi_{t+1} - 1\right)\Pi_{t+1}\frac{Y_{t+1}}{Y_t}\right]. \tag{3.12}$$

A detailed derivation of equation (3.12) is in Appendix B.1.3.

3.3 Monetary and fiscal policy

We assume that the central bank follows a simple Taylor rule:

$$1 + i_t = (1+i)\,\Pi_t^{\mu_\Pi} \tilde{Y}_t^{\mu_Y} (1+\varepsilon_t^i), \qquad \varepsilon_t^i \sim \mathcal{N}(0, \sigma_i^2), \tag{3.13}$$

where $\tilde{Y}_t = Y_t/Y_{n,t}$ is the (gross) output gap and $Y_{n,t}$ is potential output, μ_Π is the coefficient on inflation, μ_Y is the coefficient on the output gap, and ε_t^i is a monetary policy shock. Lastly, the fiscal authority follows a balanced budget rule: $T_t = \tau_P Y_t +$

Parameters		Value	Source/Target
	Households		
β	Subjective discount factor	0.99	4% s.s. real interest rate
γ	Coefficient of relative risk aversion	1	Standard value
φ	Inverse Frisch elasticity	1	Standard value
γ_W	Rotemberg wage adjustment costs	479.0	Wage duration of 4 quarters
ε_W	Elasticity of substitution, labor inputs	6	Standard value
	Firms		
γ_P	Rotemberg price adjustment costs	29.4	Price duration of 3 quarters
ε	Elasticity of substitution, intermediate goods	6	Standard value
ϕ	Elasticity of substitution, production inputs	0.003	Impulse responses (Figure 2.3)
α	CES share parameter	0.95	Hassler, Krusell, and Olovsson (2021)
	Monetary and fiscal authority		
μ_Π	Taylor coefficient on inflation	1.5	Taylor (1993)
μ_Y	Taylor coefficient on output gap	0.5	Taylor (1993)
τ_P	Production subsidy	$\frac{1}{\varepsilon-1}$	Erceg et al. (2000)
τ_W	Labor subsidy	$\frac{1}{\varepsilon_W-1}$	Erceg et al. (2000)
	Exogenous processes		
μ_X	Mean production of non-labor input	1	Normalization
ρ_X	Autoregressive coefficient, supply shock	0	*iid* assumption
σ_X	Standard deviation, supply shock	0.0052	Impulse responses (Figure 2.3)
σ_i	Standard deviation, monetary policy shock	0.0049	Impulse responses (Figure 2.3)

Table 3.1. Calibration.

$\tau_W w_t L_t$.

3.4 Market clearing

The goods market clearing condition is given by:

$$Y_t = C_t + Y_t^P + Y_t^W. \tag{3.14}$$

3.5 Solution method

We solve the nonlinear model with global methods. Specifically, we use a time iteration algorithm, see Coleman (1989, 1990). The shocks are discretized according to the Rouwenhorst (1995) method, with each shock represented by an 11-state Markov chain. The details of the solution algorithm are laid out in Appendix B.3.

3.6 Calibration

Table 3.1 summarizes the calibration. The economy is calibrated in four parts: Households, firms, the fiscal and monetary authority, and the exogenous shock processes, respectively. The time unit is quarterly.

We use standard parameter values for household preferences. We set $\beta = 0.99$, implying an annual steady state real interest rate of 4 percent. We set the coefficient of relative risk aversion, γ, and the inverse Frisch elasticity, φ, to unity. The elasticity of substitution with respect to labor inputs is set to $\varepsilon_w = 6$. In the absence of a labor subsidy, this would imply a steady state wage markup of 20 percent, which is standard in the literature. The Rotemberg wage adjustment cost parameter, $\gamma_W = 479$, is calibrated to be equivalent to a Calvo wage duration of four quarters in the linearized version of the model, as in Galí (2015).

Turning to firms, we calibrate the Rotemberg price adjustment cost parameter to $\gamma_P = 29.4$, which is consistent with a Calvo price duration of three quarters in the linearized version of the model. This duration is, in turn, consistent with the microeconometric evidence in Nakamura and Steinsson (2008). The elasticity of substitution with respect to intermediate goods is set to $\varepsilon = 6$, which is a standard value. We calibrate the elasticity of substitution between labor and the non-labor production input, ϕ, to match the empirical evidence presented in Figure 2.3. Specifically, we set $\phi = 0.003$, such that a one-standard-deviation expansionary monetary shock raises inflation by 50 basis points in the nonlinear model, as in the empirical impulse response shown in Figure 2.3. This value is, in turn, consistent with the empirical evidence in Hassler, Krusell, and Olovsson (2021), who obtain near-zero estimates of the elasticity of substitution between capital/labor and energy in the US.[16] Following Hassler, Krusell, and Olovsson (2021), we set the share parameter in the CES production function to $\alpha = 0.95$.[17]

We use the standard Taylor (1993) rule coefficients, $\mu_\Pi = 1.5$ and $\mu_Y = 0.5$. As in Erceg et al. (2000), we calibrate the production and labor subsidies, τ_P and τ_W, to obtain an efficient steady-state allocation.

For the exogenous processes, we normalize the steady state endowment of the non-labor input, μ_X, to 1, and we assume that supply shocks are *iid*, setting $\rho_X = 0$. The standard deviations of the shocks, σ_X and σ_i, are calibrated to match the empirical impulse responses shown in Figure 2.3. Specifically, we set $\sigma_i = 0.0049$ such that a one-standard-deviation expansionary monetary shock leads to an 80 basis point reduction in the (annualized) nominal interest rate, as in the empirical impulse response shown in Figure 2.3. Similarly, the value $\sigma_X = 0.0052$ implies that a one-standard-deviation negative supply shock raises (annualized) inflation by 60 basis points in our model, as in the empirical impulse response shown in Figure 2.3.

[16] Gagliardone and Gertler (2026) obtain similar results. Colombo and Toni (2025) obtain near-zero estimates of the price elasticities of natural gas demand in the euro area and the US. Appendix B.2 provides a robustness check for ϕ.

[17] This yields a steady-state cost share of the non-labor input of 1.2 percent in our model.

4. Quantitative analysis

This section demonstrates that the nonlinear model can generate inflation plucking cycles similar to those observed in the data in Section 2.1. We also show that the model generates asymmetric impulse responses to both monetary shocks and supply shocks that are consistent with the empirical impulse responses from Section 2.2.

4.1 Kinked marginal costs

To clarify the source of the inflation plucking cycles in the model, note that the NKPC (3.12) implies a quasi-linear relationship between inflation and marginal costs. Marginal costs, however, are highly nonlinear in the production inputs, X_{it} and L_{it}, as $\phi \to 0$. Proposition 1 summarizes this mechanism.

Proposition 1. ***Kinked marginal costs.*** *As $\phi \to 0$, the following marginal cost function arises*

$$\lim_{\phi \to 0} mc_{it} = \begin{cases} w_t & \text{if } X_{it} > L_{it}, \\ \frac{w_t}{\alpha} & \text{if } X_{it} = L_{it} \\ \infty & \text{if } X_{it} < L_{it}. \end{cases} \tag{4.1}$$

Proof. *See Appendix B.1.5.* ■

As ϕ approaches 0, that is, as labor and the non-labor input become perfect complements, the marginal cost function becomes highly nonlinear. When X_{it} is abundant, i.e. when $X_{it} > L_{it}$, marginal costs equal the real wage w_t. But when X_{it} is relatively scarce, i.e., when $X_{it} < L_{it}$, the marginal product of labor approaches zero, and marginal costs explode. This asymmetry in the marginal cost function drives the inflation plucking cycles in the model.

4.2 Inflation plucking cycles in the model

The upper panel in Figure 4.1 shows two inflation time series snippets of 100 quarters each from two model simulations.[18] One simulation is from the fully nonlinear model (solved with global methods), and the other simulation is from the model solved with a first-order perturbation approximation. Both models use the parameter values from Table 3.1 and the same series of monetary shocks and supply shocks.

Figure 4.1 shows that inflation in the linear model fluctuates symmetrically around its deterministic steady state value. In contrast, inflation in the nonlinear model is

[18] Each simulation spans 5400 quarters, which ensures that we obtain approximately the same number of observations from the models as we have in the OECD data shown in Table 2.1.

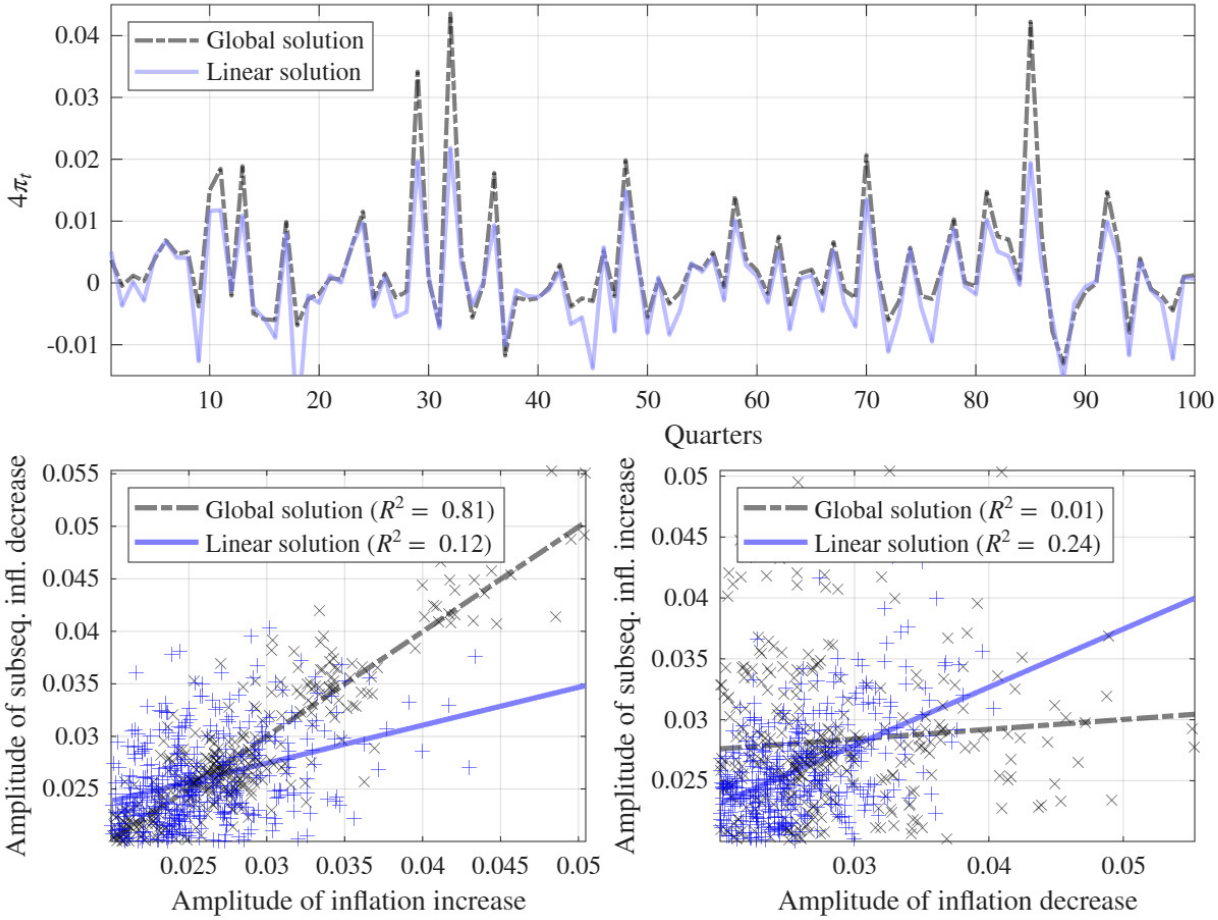


Figure 4.1. Inflation plucking cycles. This figure compares the linearized solution with the global solution. The upper panel shows two inflation time series of 100 quarters each. The lower panels display the model-implied plucking property of inflation from two simulations of 5400 quarters each, along with the simple OLS relationships.

skewed to the right. In most periods, inflation dynamics are very similar in the two models, but, occasionally, a large negative supply shock or a large expansionary monetary policy shock (or both) generates a sizable inflationary burst in the nonlinear model, which does not happen in the linear model.

In the lower panels of Figure 4.1, we repeat the exercise from Figure 2.2 in the empirical section but using model-generated data. Specifically, the lower left panel in Figure 4.1 is a scatterplot of model-implied increases in inflation against subsequent inflation reductions. Similarly, the lower right panel displays model-implied inflation reductions against subsequent increases. Both panels display OLS regression lines. The regression results from both models are summarized in Table 4.1.

In the linear model, the statistical relationships between, respectively, increase-amplitudes versus subsequent decrease-amplitudes and decrease-amplitudes versus subsequent increase-amplitudes, are roughly the same. Table 4.1 confirms that the regression coefficients and the R^2s are very similar in the two regressions (for very long

	Global solution		Linear solution	
Regressor:	Increase	Decrease	Increase	Decrease
Regressand:	Subseq. decrease	Subseq. increase	Subseq. decrease	Subseq. increase
$\hat{\beta}_1$	1.00^{***} (0.03)	0.08^{*} (0.05)	0.36^{***} (0.05)	0.48^{***} (0.04)
R^2	0.81	0.01	0.12	0.24
n	344	344	377	377

Table 4.1. Plucking property of model inflation. This table reports OLS regression results. The asterisks *** and * denote significance at the 1 and 10 percent levels, respectively.

samples, they would be strictly identical). Both the regression coefficients and the R^2s are relatively low. Thus, in the linear model, inflation amplitudes have symmetric (and relatively low) prediction power, implying no inflation plucking cycles.

In contrast, in the nonlinear model, there is a one-for-one statistical relationship between increases in inflation and subsequent reductions. This relationship is significant at the 1 percent level, and the R^2 of the regression is 0.81. On the other hand, the statistical relationship between decreases in inflation and subsequent increases is very weak. The regression coefficient, $\hat{\beta}_1 = 0.08$, is statistically significant but small, and the R^2 of the regression is close to zero. The regression results from the nonlinear model (shown in Table 4.1) are very similar to those obtained from US data (shown in Table 2.1), even though these regression coefficients were not targeted in the model calibration.

In Appendix B.2, we show that the nonlinear model's ability to reproduce the inflation plucking cycles observed in the data relies critically on the (empirically plausible) assumption that the substitution elasticity, ϕ, is close to zero. Thus, the key nonlinearity in the model, driving the inflation plucking cycles, is the high degree of complementarity between labor and the non-labor input in the production function (3.7).

4.3 Asymmetric effects of shocks

In this section, we demonstrate that the nonlinear model can generate asymmetric impulse responses to both supply shocks and monetary policy shocks that are consistent with the empirical impulse responses from Figure 2.3.

4.3.1 Monetary policy shocks

Figure 4.2 shows the impulse responses from the nonlinear model to one-standard-deviation expansionary versus contractionary monetary policy shocks. As shown, the nonlinear model generates asymmetric impulse responses that are very similar to the empirical impulse responses from Figure 2.3. In particular, an expansionary monetary

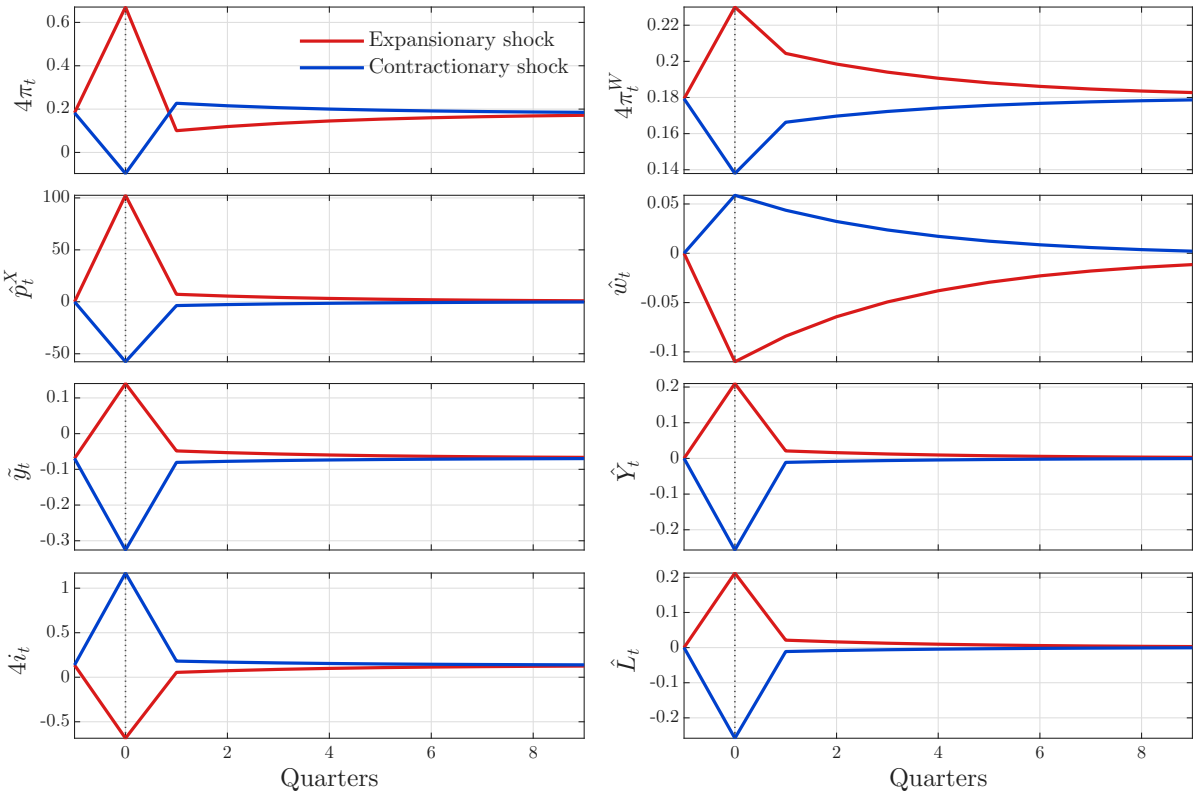


Figure 4.2. Impulse response functions. Impulse responses to one-standard-deviation expansionary (red) versus contractionary (blue) monetary policy shocks in the baseline economy with a Taylor rule. Hatted variables are denoted in percentage deviations from the risky steady state. $\tilde{y}_t$ is the output gap, defined as the percentage deviation of actual output from potential output.

policy shock produces a relatively large increase in inflation but a relatively small increase in output, whereas a contractionary monetary shock produces a relatively small reduction in inflation but a relatively large reduction in output.

Intuitively, an expansionary monetary policy shock puts upward pressure on output and inflation in the model. But since the non-labor production input is in fixed supply and cannot easily be substituted with labor, the output response becomes relatively weak, while the inflation response becomes relatively strong. Conversely, a contractionary monetary shock generates a relatively strong output response but a relatively weak inflation response. Figure 4.2 also shows that an expansionary monetary shock leads to a relatively large increase in the input price, p_t^X, and a pronounced reduction in the real wage w_t. The decline in the real wage is followed by a sustained period of positive wage inflation, consistent with the post-pandemic experience in the US and other advanced economies (IMF, 2022).

Quantitatively, the impulse responses in Figure 4.2 match the empirical impulse responses from Figure 2.3 quite well. The model is calibrated such that the nominal interest rate declines by 80 basis points and inflation increases by 50 basis points in response to an expansionary shock, as in the data in Figure 2.3. At the same time,

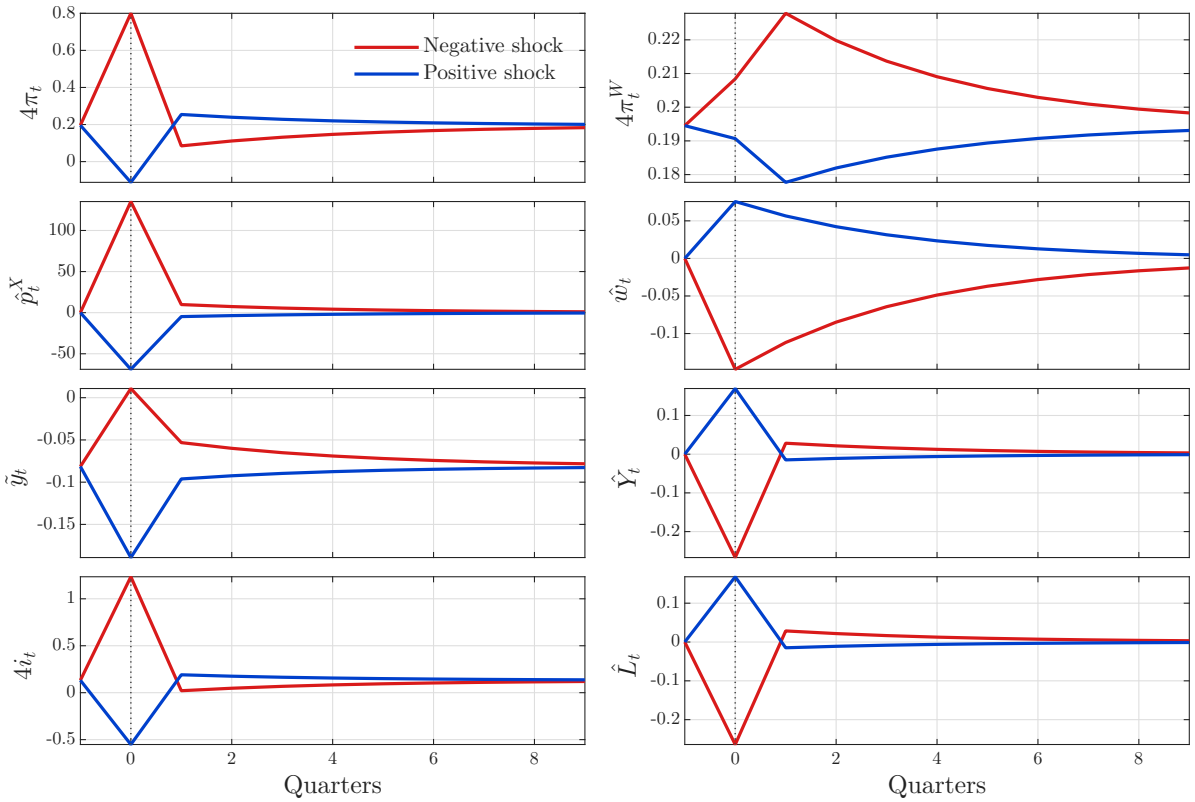


Figure 4.3. Impulse response functions. Impulse responses to one-standard-deviation negative (red) versus positive (blue) supply shocks in the baseline economy with a Taylor rule. Hatted variables are denoted in percentage deviations from the risky steady state. $\tilde{y}_t$ is the output gap, defined as the percentage deviation of actual output from potential output.

the model successfully replicates the inflation response to a contractionary monetary shock. Inflation declines by nearly 30 basis points in both the model and the data. The model can also replicate the asymmetric responses of output. In the model, output increases by 0.2 percent following an expansionary shock and declines by around 0.25 percent following a contractionary shock, closely matching the empirical impulse responses from Figure 2.3.

4.3.2 Supply shocks

Figure 4.3 shows the impulse responses from the nonlinear model to one-standard-deviation positive versus negative supply shocks. As the figure shows, the model generates asymmetric impulse responses similar to those observed in the data in Figure 2.3. In particular, a negative supply shock generates a stronger response of *both* inflation and output than a positive supply shock.

Intuitively, a negative shock to the supply of the non-labor production input leads to a large reduction in the marginal product of labor, generating a sharp drop in output and a large increase in marginal costs, which in turn raises inflation. Conversely, a positive supply shock raises output and lowers inflation, but the effect is noticeably

weaker. As with an expansionary monetary policy shock, a negative supply shock is accompanied by a large increase in the non-labor input price, p_t^X, and a sharp reduction in the real wage, w_t, which are followed by a prolonged period of positive wage inflation.

Quantitatively, the model-implied impulse responses align reasonably well with their empirical counterparts in Figure 2.3. The model is calibrated such that inflation rises by 60 basis points following a negative supply shock, consistent with the empirical impulse response. Following a positive supply shock, inflation falls by 30 basis points in the model, which is somewhat more than in the data. The output responses, however, closely match their empirical counterparts. Output declines by 0.25 percent following a negative supply shock and rises by 0.15 percent following a positive supply shock. The former is nearly identical to the median empirical response, while the latter lies well within the posterior credible bands.

4.4 Nonlinear Phillips curve

This section shows that our nonlinear model from Section 3 gives rise to a convex price Phillips curve. For illustrative purposes, we abstract from wage rigidities, setting $\gamma_W = 0$. In this special case, a first-order approximation of the model in Section 3 yields a New Keynesian Phillips Curve (NKPC) of the form:

$$\pi_t = \beta \mathbb{E}_t[\pi_{t+1}] + \kappa \tilde{y}_t, \tag{4.2}$$

where κ is the structural NKPC slope coefficient, and $\tilde{y}_t$ is the (log-linearized) output gap. In addition, with flexible wages, $\mathbb{E}_t[\pi_{t+1}]$ will be constant in our model, hence the NKPC (4.2) entails a simple linear relationship between π_t and $\tilde{y}_t$.

Figure 4.4 plots the relationship between π_t and $\tilde{y}_t$ from the linearized model conditional on supply shocks only (left panel) and on monetary policy shocks only (right panel), respectively. By construction, these two relationships are identical. The figure also shows the average values of π_t and $\tilde{y}_t$ implied by the linear model. As shown, inflation and the output gap are on average equal to their deterministic steady-state values, $\mathbb{E}[\pi_t] = 0$ and $\mathbb{E}[\tilde{y}_t] = 0$.

Figure 4.4 also shows the corresponding relationships between π_t and $\tilde{y}_t$ implied by the nonlinear model. As the figure shows, the nonlinear model yields a convex Phillips curve relationship. Negative supply shocks or expansionary monetary policy shocks generate relatively strong inflation responses but relatively muted output gap responses. In contrast, positive supply shocks or contractionary monetary shocks lead to relatively muted inflation responses but relatively strong output gap responses. As a result, the nonlinear model yields a positive inflation bias (inflation *exceeds* the cen-

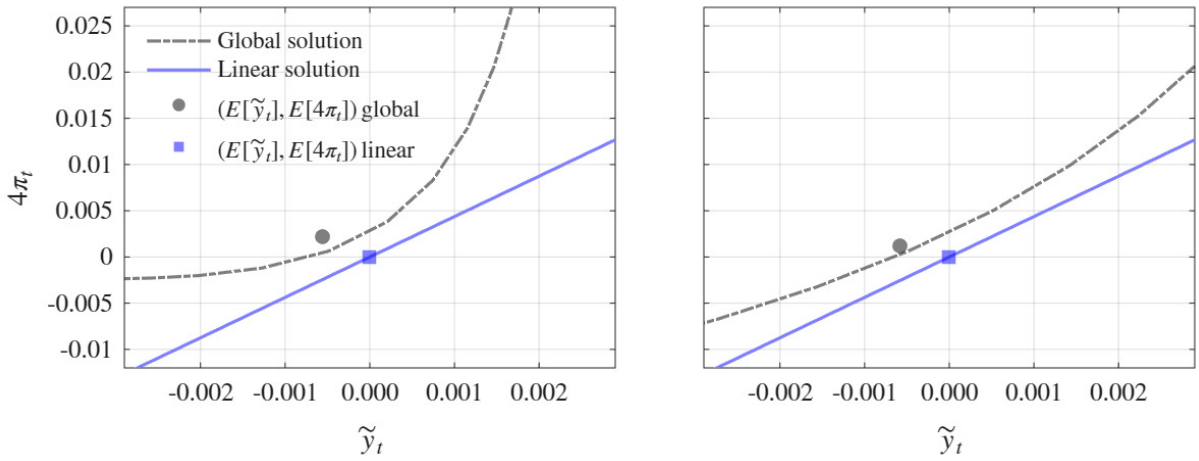


Figure 4.4. Phillips curves. The figure shows the Phillips curve relationship implied by the linear and nonlinear models with flexible wages, conditional on supply shocks (left panel) and monetary policy shocks (right panel), respectively.

tral bank's inflation target on average) and a negative output gap bias (average output falls short of its efficient level). Conditional on supply shocks only, we obtain $\mathbb{E}[4\pi_t] = 0.21\%$ and $\mathbb{E}[\tilde{y}_t] = -0.06\%$. Conditional on monetary policy shocks only, we obtain $\mathbb{E}[4\pi_t] = 0.12\%$ and $\mathbb{E}[\tilde{y}_t] = -0.06\%$. In the following section, we will show that such biases can give rise to substantial welfare losses, which, however, can be nearly eliminated by a Ramsey planner.

5. Optimal monetary policy

This section solves the Ramsey planner's problem under commitment. Then, we compare the Ramsey equilibrium with the Taylor rule equilibrium considered in the previous section.

5.1 Ramsey planner's problem

The Ramsey planner maximizes social welfare

$$\max_{\{i_t, C_t, L_t, \Pi_t, X_t, mc_t, w_t\}_{t=0}^{\infty}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\gamma}}{1-\gamma} - \frac{L_t^{1+\varphi}}{1+\varphi} \right]$$

subject to the household's Euler equation (3.3); the wage Phillips curve (3.4); the price Phillips curve (3.12); firms' labor demand (3.8); firms' non-labor demand (3.9); and the goods market equilibrium (3.14). The complete set of Ramsey equilibrium equations is listed in Appendix B.1.4.

The state space of the model with a Ramsey planner is too large for a global so-

lution. However, in Appendix B.3, we show that a fifth-order perturbation approximation is very close to the global solution in the model with a Taylor rule. Therefore, in the remaining part of the analysis, we rely on a fifth-order approximation of the model.

5.2 Optimal policy response to supply shocks

How should monetary policy respond to positive versus negative supply shocks? As is well-known from the textbook New Keynesian model, the so-called "divine coincidence" breaks down when wages are sticky, hence the flex-price allocation cannot be attained. In this case, the Ramsey planner faces a trade-off between stabilizing price inflation, wage inflation, and the output gap (Galí, 2015).

Figure 5.1 shows the impulse responses to a large positive versus a large negative supply shock when monetary policy follows a Taylor rule versus the Ramsey policy, respectively. In response to a negative supply shock, the Ramsey planner allows for moderate price inflation (and wage deflation), thus facilitating a reduction in the real wage. Due to the sluggish response of the real wage, actual output declines more than potential output, generating a negative output gap. A positive supply shock generates qualitatively similar dynamics but with the opposite sign.

Turning to the asymmetries, Figure 5.1 shows that the Ramsey policy responds *asymmetrically* to supply shocks: The real interest rate increases more in response to a negative shock than it declines in response to a positive shock.[19] The top-left panel in Figure 5.1 shows that the aggressive response to negative supply shocks serves to reduce inflation substantially compared to the Taylor rule. The top-right panel shows that by stabilizing inflation, the Ramsey planner stabilizes the real wage, which declines much less in response to a negative shock than under a Taylor rule. Finally, the bottom-left panel illustrates the favorable trade-off that the Ramsey planner faces in response to a negative supply shock: Stabilizing inflation does not require a large reduction in the output gap. This is due to the convexity of the Phillips curve: On the steep part of the Phillips curve, small reductions in output generate large reductions in inflation.

As Figure 5.1 shows, the Ramsey policy entails a less aggressive response to large positive supply shocks than to large negative supply shocks. Again, the intuition is two-fold. First, large positive supply shocks do not lead to large drops in price and wage inflation. Second, reductions in the real interest rate (which raise output) have virtually no impact on inflation. Again, this can be attributed to the convex Phillips

[19] Similarly, the Taylor rule entails an asymmetric, though less aggressive, response to supply shocks. Intuitively, because the Taylor rule (3.13) places greater weight on inflation than on the output gap, a negative supply shock—which raises inflation disproportionately—generates a stronger policy-rate response than a positive supply shock.

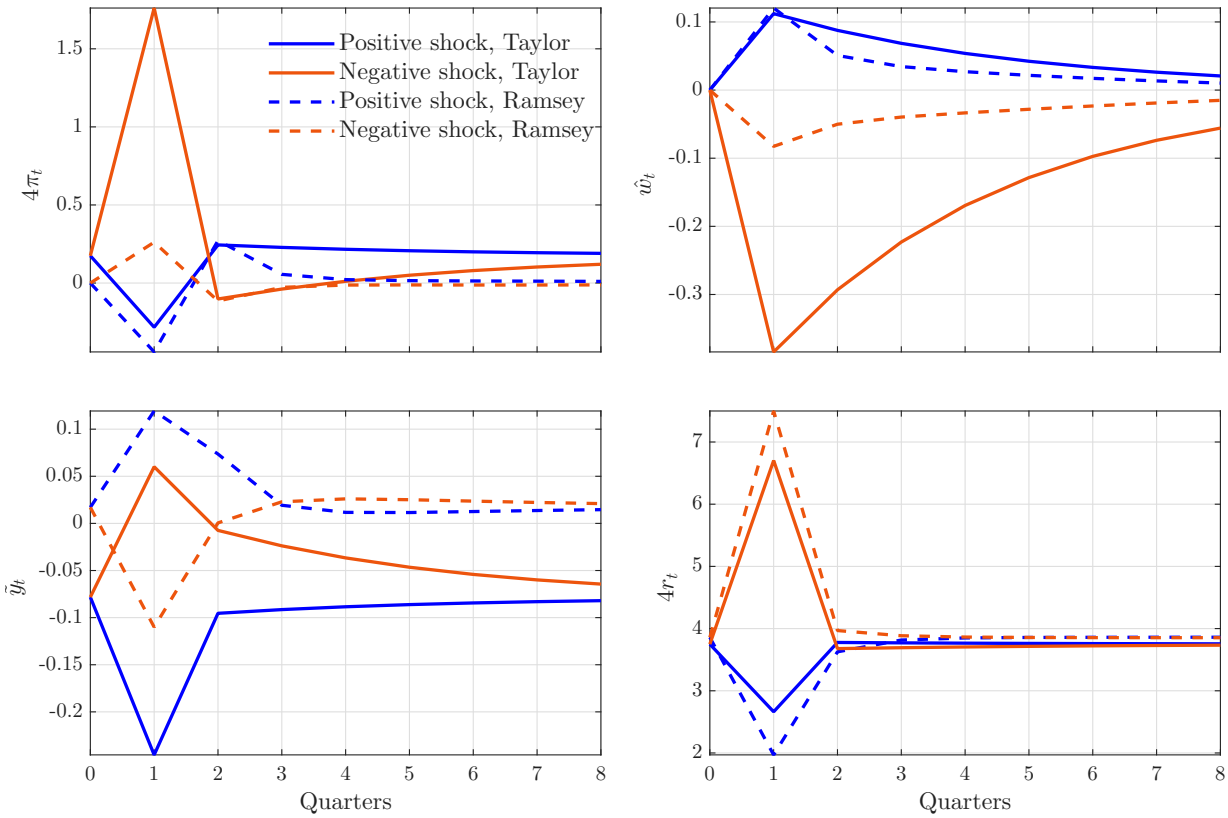


Figure 5.1. Impulse responses, Taylor rule versus Ramsey policy. Impulse responses to large (2 std. dev.) positive and negative supply shocks under the Taylor rule and the Ramsey policy, respectively. The model is solved using a fifth-order perturbation approximation. Hatted variables are denoted in percentage deviations from the risky steady state. $\tilde{y}_t$ is the output gap, defined as the percentage deviation of actual output from potential output.

curve: On the flat part of the Phillips curve, large increases in output generate small increases in inflation.

A key takeaway from Figure 5.1 concerns the risky steady state. Under a Taylor rule, the highly asymmetric response of inflation to positive versus negative supply shocks translates into a positive inflation bias and a negative output gap bias. Figure 5.1 shows that the Ramsey planner corrects these biases: Both inflation and the output gap are indistinguishable from zero in the risky steady state. Thus, a relatively strong asymmetric response to supply shocks serves to dampen the inflation plucking cycles, reduce the average rate of inflation and raise the average level of output. In the following section, we show that such level effects can generate large welfare gains, thus rationalizing the Ramsey policy.

5.3 Welfare gains from stabilization policy

In standard macroeconomic models, including the workhorse New Keynesian model, inflation fluctuates symmetrically around the central bank's inflation target, while output fluctuates symmetrically around its natural level. In these models, stabilization

policy has no effect on average levels, hence the implied welfare gains are negligible (Lucas, 1987, 2003).[20] In contrast, in our nonlinear model, inflation exceeds the central bank's inflation target on average, while average output falls short of its average potential level. In this section, we show that these level effects make the welfare costs of business cycles considerably larger in the nonlinear model than in its linearized counterpart. Fortunately, the Ramsey planner can nearly eliminate these level effects and the associated welfare losses by responding aggressively to large negative supply shocks.

To evaluate how monetary policy impacts household welfare, we calculate the percentage of consumption needed to compensate households for living in an economy with sticky prices and wages relative to the flexible price-wage benchmark under different monetary policy regimes. Specifically, for each monetary policy regime, we solve for the value of Λ that yields

$$\mathbb{E}\left[\frac{\left(\left(1+\Lambda\right)C_t\right)^{1-\gamma}}{1-\gamma}-\frac{L_t^{1+\varphi}}{1+\varphi}\right]=\mathbb{E}\left[\frac{C_{n,t}^{1-\gamma}}{1-\gamma}-\frac{L_{n,t}^{1+\varphi}}{1+\varphi}\right],$$

where $\mathbb{E}$ is the unconditional expectation operator, and $C_{n,t}$ and $L_{n,t}$ are consumption and employment in the flexible price-wage economy, respectively. For this exercise, we only consider the welfare losses from supply shocks, as monetary policy shocks are policy mistakes by construction.

Figure 5.2 shows the relationship between the standard deviation of the supply shock, σ_X, and the welfare loss, Λ, in the linear and nonlinear models. In the linear model with a Taylor rule, the welfare loss remains virtually constant as we increase the value of σ_X. In contrast, the welfare loss increases rapidly in the nonlinear model. What explains this difference? The four lower panels in Figure 5.2 display the unconditional means and standard deviations of inflation and the output gap implied by the two models. While the standard deviations, $SD(\pi_t)$ and $SD(\tilde{y}_t)$, are broadly similar in the two models with a Taylor rule, the unconditional means, $\mathbb{E}(\pi_t)$ and $\mathbb{E}(\tilde{y}_t)$, differ substantially.

Specifically, in the linear model, $\mathbb{E}(\pi_t)$ and $\mathbb{E}(\tilde{y}_t)$ remain constant as we increase the size of σ_X. But in the nonlinear model, $\mathbb{E}(\pi_t)$ increases, while $\mathbb{E}(\tilde{y}_t)$ declines. Taken together, this illustrates that the rising welfare losses in the nonlinear model with a Taylor rule are almost exclusively driven by level effects, which, by construction, are absent in the linear model.[21]

Figure 5.2 shows that the welfare losses in the nonlinear model are much lower

[20] Lucas (2003) showed that, under log utility, the welfare costs of business cycle fluctuations in US consumption over the period 1947-2001 were 0.05% of perpetual consumption.

[21] We have verified that the welfare losses in the linear and nonlinear models with a Taylor rule are virtually identical if we disregard level effects.

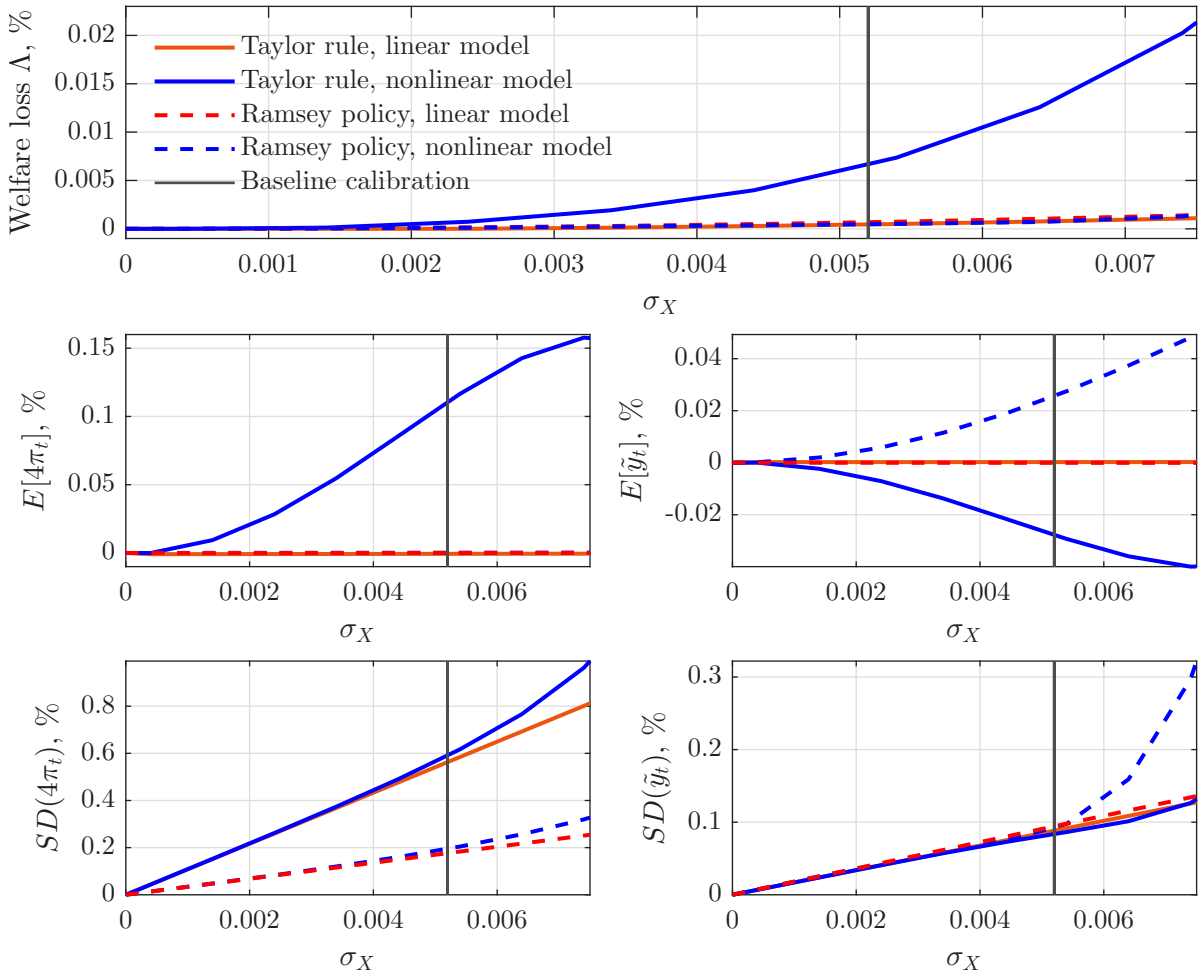


Figure 5.2. Welfare loss. Consumption-equivalent welfare loss relative to welfare when prices and wages are completely flexible. The nonlinear model is solved using a fifth-order perturbation approximation.

when monetary policy is conducted by the Ramsey planner. In fact, the welfare losses in this model coincide with the welfare losses in its linearized counterpart.[22] Intuitively, the Ramsey planner's asymmetric response to positive versus negative supply shocks serves to reduce the average rate of inflation and raise the average level of output in the model. As Figure 5.2 shows, the Ramsey planner fully corrects the inflation bias that arises under a Taylor rule, while accepting a small positive output gap bias.[23]

6. Conclusion

This paper documents that inflation rates in nearly all OECD countries display "plucking" cycles: Increases in inflation are followed by decreases of similar amplitude. But

[22]Note that the welfare losses in the linear model with a Taylor rule and a Ramsey planner, respectively, coincide in Figure 5.2.

[23]The latter arises from the slight asymmetry in the output gap responses under the Ramsey policy shown in Figure 5.1.

the amplitude of a decrease does not predict the amplitude of the subsequent increase. We provide econometric evidence that both monetary policy shocks and supply shocks have asymmetric effects on inflation that are consistent with this plucking property: Negative supply shocks and expansionary monetary policy shocks generate relatively large increases in inflation, while positive supply shocks and contractionary monetary shocks generate relatively small reductions. Our econometric evidence suggests that capacity constraints help explain these asymmetries. Specifically, we find that the energy and industry shortage measure developed by Caldara, Iacoviello, and Yu (2026) responds strongly to negative supply shocks and expansionary monetary policy shocks, indicating binding capacity constraints, but weakly to positive supply shocks and contractionary monetary policy shocks.

Motivated by the empirical evidence, we extend an otherwise standard New Keynesian model with a scarce non-labor input with low substitutability in production. We show that the fully nonlinear version of the model—solved with global methods—can help explain our empirical findings. The model gives rise to a convex price Phillips curve, which, coupled with a standard Taylor rule for monetary policy, generates a positive inflation bias (average inflation exceeds the central bank's inflation target) and a negative output gap bias (average output falls short of its potential level). These level effects—which by construction are absent in linear models—can generate substantial welfare losses. We show that optimal monetary policy responds more aggressively to large negative supply shocks than to large positive supply shocks. This policy dampens the inflation plucking cycles, lowers the inflation bias, and raises the average output level, yielding sizable welfare gains.

Appendices

A. Empirical results

A.1 Data

The data consist of 4-quarter inflation rates from the OECD.[24] Inflation data for most countries cover the period from 1960Q1 to 2024Q2. We consider three samples of data:

- **Full sample:** Using all available data since 1960Q1. Applied to our country-specific regressions in Table A.2-A.3.
- **Baseline sample:** For our baseline cross-country analysis, we exclude inflation rates over 50 percent per year. If inflation exceeds this threshold, the country-specific subsample begins at the next inflation trough, excluding all earlier observations.
- **Low-inflation regimes sample:** We define low-inflation regimes as those where inflation remains below 10 percent throughout the sample. If inflation exceeds this threshold, the country-specific subsample begins at the next inflation trough, excluding all prior observations.

See Table A.1 for a summary of the start and end dates of each country's inflation series for various analyses.

Using these datasets, we run various versions of the simple linear regression

$$y_t = \beta_0 + \beta_1 x_t + \epsilon_t, \tag{A.1}$$

where x_t and y_t are adjacent amplitudes of opposing direction. We consider two cases:

- **Increase versus subsequent decrease:** x_t is the amplitude of an increase in inflation while y_t is the amplitude of the subsequent decrease.
- **Decrease versus subsequent increase:** x_t is the amplitude of a decrease in inflation while y_t is the amplitude of the subsequent increase.

[24] The data can be accessed at `data-explorer.oecd.org`.

Country	Full sample	Baseline sample	"Low-inflation regime" sample
Australia	1960Q1-2024Q2	1960Q1-2024Q2	1984Q4-2024Q2
Austria	1960Q1-2024Q2	1960Q1-2024Q2	—
Belgium	1960Q1-2024Q2	1960Q1-2024Q2	—
Canada	1960Q1-2024Q2	1960Q1-2024Q2	1985Q1-2024Q2
Chile	1971Q1-2023Q4	1979Q1-2023Q4	—
Colombia	1971Q1-2024Q2	1971Q1-2024Q2	—
Costa Rica	1977Q1-2021Q4	1984Q2-2021Q4	2009Q4-2021Q4
Czech Republic	1992Q1-2024Q2	1992Q1-2024Q2	—
Denmark	1967Q1-2024Q2	1967Q1-2024Q2	1986Q1-2024Q2
Estonia	1998Q1-2024Q2	1998Q1-2024Q2	—
Finland	1960Q1-2024Q2	1960Q1-2024Q2	1986Q2-2024Q2
France	1960Q1-2024Q2	1960Q1-2024Q2	1999Q1-2024Q2
Germany	1960Q1-2024Q2	1960Q1-2024Q2	1960Q1-2024Q2
Greece	1960Q1-2024Q2	1960Q1-2024Q2	—
Hungary	1981Q1-2024Q2	1981Q1-2024Q2	—
Iceland	1960Q1-2024Q2	1984Q4-2024Q2	2011Q1-2024Q2
Ireland	1976Q1-2024Q2	1976Q1-2024Q2	1988Q2-2024Q2
Israel	1971Q1-2024Q2	1986Q4-2024Q2	1998Q3-2024Q2
Italy	1960Q1-2024Q2	1960Q1-2024Q2	—
Japan	1960Q1-2021Q2	1960Q1-2021Q2	1979Q1-2021Q2
Latvia	1992Q1-2024Q2	1993Q4-2024Q2	—
Lithuania	1992Q1-2024Q2	2001Q1-2024Q2	—
Luxembourg	1960Q1-2024Q2	1960Q1-2024Q2	1986Q4-2024Q2
Mexico	1969Q1-2024Q2	1989Q3-2024Q2	2005Q4-2024Q2
Netherlands	1960Q2-2024Q2	1960Q2-2024Q2	—
New Zealand	1960Q1-2023Q3	1960Q1-2023Q3	1989Q1-2023Q3
Norway	1960Q1-2024Q2	1960Q1-2024Q2	1985Q4-2024Q2
Poland	1996Q1-2024Q2	1996Q1-2024Q2	—
Portugal	1960Q1-2024Q2	1960Q1-2024Q2	2000Q1-2024Q2
Slovakia	1992Q1-2024Q2	1992Q1-2024Q2	—
Slovenia	1981Q1-2024Q2	1994Q1-2024Q2	—
South Korea	1960Q1-2023Q3	1960Q1-2023Q3	1987Q1-2023Q3
Spain	1960Q1-2024Q2	1960Q1-2024Q2	—
Sweden	1960Q1-2024Q2	1960Q1-2024Q2	—
Switzerland	1960Q1-2024Q2	1960Q1-2024Q2	1978Q4-2024Q2
Turkey	1960Q1-2024Q2	—	—
United Kingdom	1960Q1-2024Q2	1960Q1-2024Q2	1983Q2-2024Q2
United States	1960Q1-2024Q2	1960Q1-2024Q2	1986Q4-2024Q2

Table A.1. Data samples. This table reports the various country-specific subsamples used in the empirical analysis.

A.2 Country-specific regressions

We run country-specific regressions of equation (A.1) using the full sample. The results are summarized in Table A.2 and A.3.

Regressor:		Increase				Decrease			
Regressand:		Subseq. decrease				Subseq. increase			
Country	Period	$\hat{\beta}_0$	$\hat{\beta}_1$	R^2	n	$\hat{\beta}_0$	$\hat{\beta}_1$	R^2	n
Australia	1960Q1-2024Q2	3.68**	0.22	0.07	13	4.78**	0.04	0.00	13
		(1.30)	(0.23)			(1.79)	(0.34)		
Austria	1960Q1-2024Q2	2.56**	0.42*	0.37	9	4.76	0.02	0.00	9
		(0.86)	(0.18)			(2.98)	(0.65)		
Belgium	1960Q1-2024Q2	0.85	0.85***	0.78	8	9.70**	−0.54	0.22	7
		(1.18)	(0.16)			(2.55)	(0.38)		
Canada	1960Q1-2024Q2	3.09*	0.38	0.23	8	6.76**	−0.31	0.05	8
		(1.36)	(0.24)			(2.48)	(0.46)		
Chile	1971Q1-2023Q4	42.41	0.46**	0.44	11	10.98**	0.05*	0.25	11
		(32.84)	(0.16)			(4.13)	(0.03)		
Colombia	1971Q1-2024Q2	4.42	0.56**	0.30	13	6.78**	0.26	0.07	13
		(2.57)	(0.24)			(2.94)	(0.26)		
Costa Rica	1977Q1-2021Q4	1.32	0.93***	0.99	12	7.43***	0.04	0.05	11
		(0.96)	(0.03)			(1.74)	(0.06)		
Czech Republic	1992Q1-2024Q2	1.95	0.94**	0.73	5	14.37**	−0.74	0.38	5
		(2.09)	(0.26)			(4.10)	(0.42)		
Denmark	1967Q1-2024Q2	1.34	0.83**	0.45	10	5.29**	0.01	0.00	10
		(1.73)	(0.29)			(1.82)	(0.27)		
Estonia	1998Q1-2024Q2	0.24	1.10*	0.82	4	20.80	−1.14	0.23	4
		(1.89)	(0.26)			(8.66)	(1.03)		
Finland	1960Q1-2024Q2	2.04	0.72*	0.37	9	9.13***	−0.36	0.20	9
		(2.26)	(0.31)			(1.83)	(0.24)		
France	1960Q1-2024Q2	3.77	0.32	0.08	6	6.54*	−0.22	0.06	6
		(2.74)	(0.44)			(2.35)	(0.35)		
Germany	1960Q1-2024Q2	1.37	0.72*	0.46	7	4.24	0.17	0.02	7
		(1.32)	(0.29)			(2.38)	(0.50)		
Greece	1960Q1-2024Q2	4.04**	0.54***	0.57	12	12.17**	−0.36	0.07	12
		(1.61)	(0.14)			(4.10)	(0.39)		
Hungary	1981Q1-2024Q2	2.74	0.70**	0.39	10	12.30**	−0.30	0.07	10
		(2.78)	(0.28)			(3.88)	(0.36)		
Iceland	1960Q1-2024Q2	2.49	0.83***	0.53	20	13.10***	0.17	0.04	20
		(3.66)	(0.17)			(4.29)	(0.19)		
Ireland	1976Q1-2024Q2	12.99***	−0.79	0.28	8	5.53*	0.14	0.04	8
		(3.19)	(0.45)			(2.42)	(0.24)		
Israel	1971Q1-2024Q2	−9.02	1.28***	0.96	17	34.73	−0.07	0.01	17
		(5.52)	(0.07)			(20.06)	(0.18)		
Italy	1960Q1-2024Q2	3.98*	0.50**	0.52	8	11.95**	−0.47	0.10	8
		(1.74)	(0.17)			(4.46)	(0.49)		
Japan	1960Q1-2021Q2	0.11	1.08***	0.92	11	5.46**	−0.06	0.00	11
		(0.63)	(0.09)			(2.01)	(0.27)		
Latvia	1992Q1-2024Q2	1.68	1.68***	1.00	6	10.87**	−0.00	0.05	6
		(5.55)	(0.02)			(3.16)	(0.01)		
Lithuania	1992Q1-2024Q2	119.53	0.96*	0.43	6	12.60	0.03	0.19	6
		(111.23)	(0.45)			(10.79)	(0.03)		
Luxembourg	1960Q1-2024Q2	−0.83	1.14**	0.64	6	7.07**	−0.12	0.03	6
		(2.21)	(0.35)			(1.85)	(0.28)		
Mexico	1969Q1-2024Q2	−1.80	1.09***	0.87	11	29.14*	0.04	0.00	11
		(6.04)	(0.12)			(13.88)	(0.26)		

Table A.2. Country-specific regressions (Part 1). This table reports OLS regression results for OECD countries.*, **, and *** denote significance at the 10, 5, and 1 percent levels, respectively.

Regressor:		Increase				Decrease			
Regressand:		Subseq. decrease				Subseq. increase			
Country	Period	$\hat{\beta}_0$	$\hat{\beta}_1$	R^2	n	$\hat{\beta}_0$	$\hat{\beta}_1$	R^2	n
Netherlands	1960Q2-2024Q2	1.33	0.70^{***}	0.50	11	5.54^{**}	-0.08	0.00	10
		(1.27)	(0.21)			(2.23)	(0.46)		
New Zealand	1960Q1-2023Q3	2.35	0.62^{*}	0.26	13	4.24^{**}	0.33	0.17	12
		(2.04)	(0.29)			(1.61)	(0.21)		
Norway	1960Q1-2024Q2	1.53	0.69^{***}	0.50	13	4.67^{**}	0.11	0.01	13
		(1.12)	(0.19)			(1.61)	(0.28)		
Poland	1996Q1-2024Q2	2.92	0.87^{***}	0.79	12	4.42	0.58	0.05	11
		(1.65)	(0.13)			(6.44)	(0.76)		
Portugal	1960Q1-2024Q2	2.81	0.70^{**}	0.33	15	11.84^{***}	-0.20	0.07	15
		(2.88)	(0.26)			(2.34)	(0.20)		
Slovakia	1992Q1-2024Q2	1.06	1.01^{***}	0.97	6	5.03	0.24	0.09	6
		(0.72)	(0.07)			(3.28)	(0.30)		
Slovenia	1981Q1-2024Q2	-7.76	1.04^{***}	1.00	15	224.01	0.00	0.00	15
		(5.58)	(0.01)			(194.97)	(0.25)		
South Korea	1960Q1-2023Q3	6.33^{**}	0.32	0.11	19	6.02^{**}	0.32	0.09	19
		(2.46)	(0.21)			(2.68)	(0.23)		
Spain	1960Q1-2024Q2	0.09	1.00^{*}	0.36	9	9.85^{***}	-0.26	0.19	9
		(3.83)	(0.44)			(1.84)	(0.18)		
Sweden	1960Q1-2024Q2	0.44	0.94^{**}	0.43	13	5.26^{***}	0.08	0.01	13
		(1.64)	(0.30)			(1.48)	(0.25)		
Switzerland	1960Q1-2024Q2	0.66	0.89^{***}	0.79	9	3.34^{*}	0.23	0.05	9
		(0.76)	(0.15)			(1.66)	(0.33)		
Turkey	1960Q1-2024Q2	4.42	0.69^{***}	0.52	28	18.27^{***}	0.06	0.00	27
		(3.51)	(0.13)			(5.26)	(0.21)		
United Kingdom	1960Q1-2024Q2	2.48	0.65^{***}	0.56	10	9.88^{**}	-0.33	0.08	10
		(1.65)	(0.18)			(3.00)	(0.35)		
United States	1960Q1-2024Q2	-0.21	1.05^{***}	0.62	9	5.02^{**}	0.07	0.01	9
		(1.55)	(0.27)			(1.64)	(0.27)		

Table A.3. Country-specific regressions (Part 2). This table reports OLS regression results for OECD countries. *, **, and *** denote significance at the 10, 5, and 1 percent levels, respectively.

A.3 Plucking cycles in low-inflation regimes

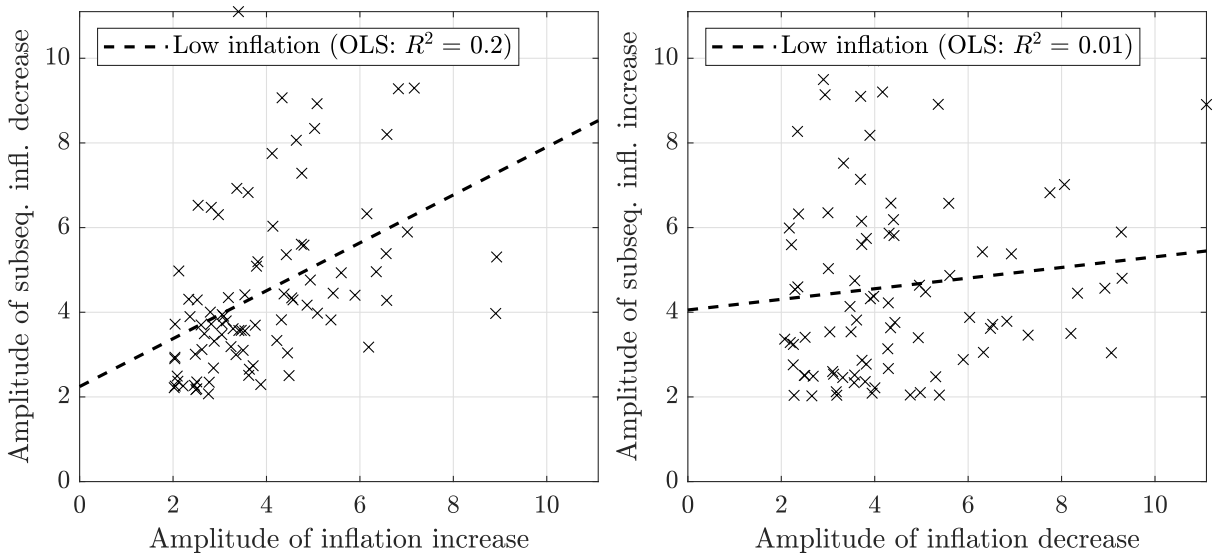


Figure A.1. Inflation plucking cycles in low-inflation regimes. This figure displays scatter plots of amplitudes of inflation cycles for low inflation regimes from pooled cross-country OECD observations. The dashed lines are univariate OLS regression lines.

This section provides empirical evidence of plucking cycles in "low-inflation regimes," which we conservatively define as countries where annual inflation has not exceeded 10 percent within the sample. Specifically, if we observe inflation rates above 10 percent, we start the country-specific subsample on the date of the subsequent inflation trough, excluding all prior observations. The resulting subsamples are listed in Table A.1 ("Low-inflation regime" sample). This highly restrictive assumption excludes around 60 percent of our inflation observations.

We run regressions of the type (A.1) where we stack cross-country observations of the restricted sample. Figure A.1 displays the resulting scatterplots of inflation increase and decrease amplitudes. Table A.4 contains the corresponding OLS regression results. As Figure A.1 and Table A.4 show, our main finding of inflation plucking cycles carries over to low-inflation regimes.

Regressor:	Increase	Decrease
Regressand:	Subseq. decrease	Subseq. increase
$\hat{\beta}_1$	0.57^{***} (0.12)	0.13 (0.12)
R^2	0.20	0.01
n	88	86

Table A.4. Plucking property in low-inflation regimes. This table reports OLS regression results for "low-inflation regimes." The asterisk *** denotes significance at the 1 percent level.

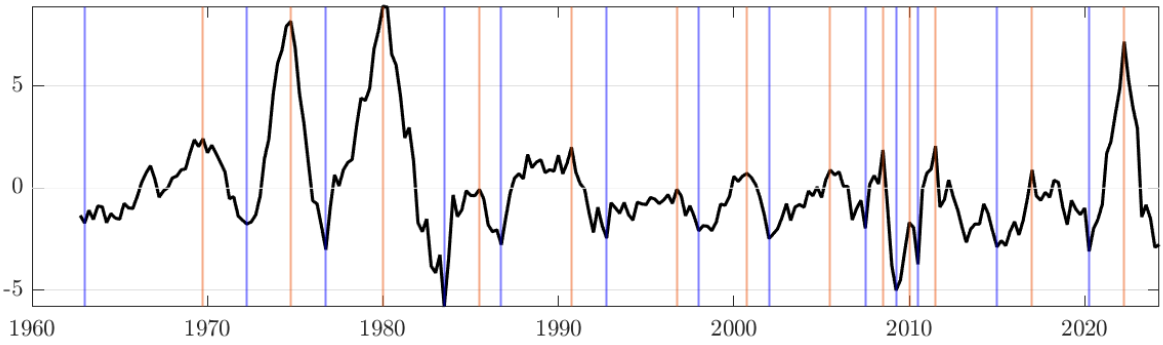


Figure A.2. De-trended US inflation. This figure displays quarterly data on US Hamilton-filtered de-trended CPI inflation along with marked inflation peaks (red) and troughs (blue).

A.4 Plucking cycles with de-trended inflation

This section shows that our baseline findings from Section 2 are robust to using de-trended instead of raw inflation data. For this purpose, we apply the Hamilton (2017) filter to the OECD inflation data. Since the data is quarterly, we set a lead length of 8 and a lag length of 4, as proposed by Hamilton (2017). Figure A.2 shows the resulting de-trended inflation data for the US, along with our identified peaks and troughs.

Figure A.3 reproduces Figure 2.2 in the main text using de-trended inflation data. The corresponding OLS regression results are shown in Table A.5. Again, we find strong evidence of inflation plucking cycles, both in the US and in the OECD countries.

Hamilton filter	United States		Cross-country OECD	
Regressor:	Increase	Decrease	Increase	Decrease
Regressand:	Subseq. decrease	Subseq. increase	Subseq. decrease	Subseq. increase
$\hat{\beta}_1$	1.23^{***} (0.15)	0.28 (0.23)	0.71^{***} (0.04)	0.11^{***} (0.04)
R^2	0.85	0.11	0.42	0.01
n	12	12	418	416

Table A.5. Plucking property of de-trended inflation. This table reports OLS regression results. The asterisk *** denotes significance at the 1 percent level.

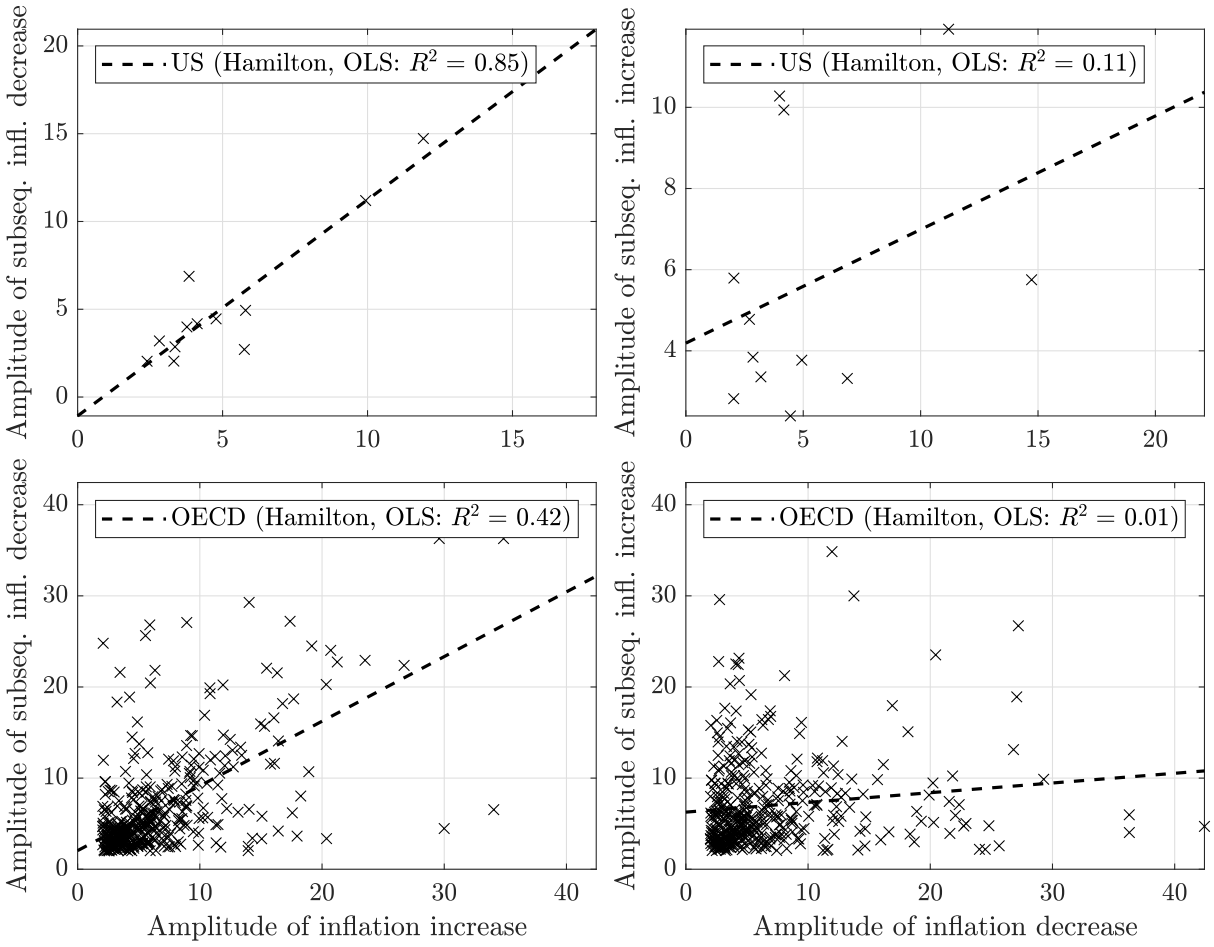


Figure A.3. Inflation plucking cycles (Hamilton filter). This figure displays scatter plots of amplitudes of de-trended inflation cycles for the US (upper panels) and the OECD countries (lower panels).

A.5 Details of FAIR estimation

We estimate equation (2.4) from the main paper, which we repeat here for convenience:

$$\mathbf{y}_t = \sum_{h=0}^{H} \left[\boldsymbol{\psi}_h^+ \left(\boldsymbol{\varepsilon}_{t-h} \odot \mathbf{1}_{\boldsymbol{\varepsilon}_{t-h}>0} \right) + \boldsymbol{\psi}_h^- \left(\boldsymbol{\varepsilon}_{t-h} \odot \mathbf{1}_{\boldsymbol{\varepsilon}_{t-h}<0} \right) \right], \tag{A.2}$$

where $\boldsymbol{\psi}_h^+$ and $\boldsymbol{\psi}_h^-$ are lag matrices of coefficients for, respectively, positive and negative shocks, and $\odot$ denotes element-wise multiplication. Each element of $\boldsymbol{\psi}_h^+$, denoted $\psi^+(h)$, can be approximated by

$$\psi^+(h) = \sum_{n=1}^{N} a_n^+ \, e^{-\left(\frac{h-b_n^+}{c_n^+}\right)^2}, \quad \forall h \in (0, H] \tag{A.3}$$

where a_n^+, b_n^+ and c_n^+ are parameters to be estimated. A corresponding expression holds for $\boldsymbol{\psi}_h^-$.

Our model includes (log) real GDP, the CPI inflation rate, the (proxy) federal funds rate, and the energy/industry shortage index (in logs). We allow for an intercept and a quintic time trend in each equation. We estimate the model with Bayesian methods, using a Metropolis-Hastings algorithm to approximate the posterior distribution. Following Barnichon and Matthes (2018), we use loose Normal priors on the a, b, and c coefficients with means obtained by matching the impulse responses obtained from an estimated VAR and with standard deviations $\sigma_a = 10$ ppt, $\sigma_b = 10$ quarters, and $\sigma_c = 20$ quarters. We set the lag length to $H = 40$ quarters. To reduce the parameter space, we only allow for asymmetry in the impulse response functions to one shock at a time.

B. New Keynesian model

B.1 Details of the New Keynesian model

B.1.1 Households

The corresponding Lagrangian to the j-th household's problem, that is, to maximize lifetime utility (3.1) subject to (3.2), equals

$$\mathcal{L} = \mathbb{E}_t \left\{ \sum_{k=0}^{\infty} \beta^k \left[\frac{C_{jt+k}^{1-\gamma}}{1-\gamma} - \frac{{L_{jt+k}}^{1+\varphi}}{1+\varphi} + \lambda_{jt+k} \left[w_{jt+k} L_{jt+k} + b_{jt+k} + d_{jt+k} - \Upsilon_{jt+k}^{W} - C_{jt+k} - \frac{(1+i_{t+k-1})}{\Pi_{t+k}} b_{jt+k-1} \right] \right] \right\}.$$

The households choose C_{jt}, b_{jt}, and w_{jt}. The first-order conditions are

$$\begin{aligned}
\frac{\partial \mathcal{L}}{\partial C_{jt}} &= C_{jt}^{-\gamma} - \lambda_{jt} = 0, \\
\frac{\partial \mathcal{L}}{\partial b_{jt}} &= \lambda_{jt} - \mathbb{E}_t \left[\beta \lambda_{jt+1} \frac{(1+i_t)}{\Pi_{t+1}} \right] = 0, \\
\frac{\partial \mathcal{L}}{\partial w_{jt}} &= -{L_{jt}}^{\varphi} \frac{\partial L_{jt}}{\partial w_{jt}} + \lambda_{jt} \left[L_{jt} + w_{jt} \frac{\partial L_{jt}}{\partial w_{jt}} - \frac{\partial \Upsilon_{jt}^{W}}{\partial w_{jt}} \right] - \mathbb{E}_t \left[\beta \lambda_{jt+1} \frac{\partial \Upsilon_{jt+1}^{W}}{\partial w_{jt}} \right] = 0,
\end{aligned}$$

with

$$\begin{aligned}
\frac{\partial L_{jt}}{\partial w_{jt}} &= -\varepsilon_W \left(w_{jt}/w_t \right)^{-\varepsilon_W - 1} L_t / w_t, \\
\frac{\partial \Upsilon_{jt}^{W}}{\partial w_{jt}} &= \gamma_W \left(\Pi_t^W - 1 \right) \Upsilon_t \Pi_t / w_{jt-1}, \\
\frac{\partial \Upsilon_{jt+1}^{W}}{\partial w_{jt}} &= -\gamma_W \left(\Pi_{t+1}^W - 1 \right) \Upsilon_{t+1} \Pi_{t+1}^W / w_{jt}, \\
\Pi_t^W &= \Pi_t w_{jt} / w_{jt-1}.
\end{aligned}$$

By applying symmetry and simplifying the expressions, we obtain the wage Phillips curve (3.4) and the Euler equation (3.3).

B.1.2 Final goods producers

This sector produces the final goods for households and is characterized by perfect competition. The final goods producer uses this technology

$$Y_t = \left(\int_0^1 Y_{it}^{\frac{\varepsilon-1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}}, \qquad \varepsilon > 1,$$

and maximizes per-period profits with respect to intermediate inputs, Y_{it}

$$\max_{Y_{it}} P_t Y_t - \int_0^1 P_{it} Y_{it} di.$$

Reorganizing the first-order condition yields the demand for the i-th intermediate input.

$$Y_{it} = \left(P_{it} / P_t \right)^{-\varepsilon} Y_t.$$

B.1.3 Intermediate goods producers

Each period, firm i minimizes costs with respect to its inputs. The corresponding Lagrangian is

$$\mathcal{L} = L_{it} w_t + p_t^X X_{it} + mc_{it} \left[\overline{Y}_{it} - \left(\alpha L_{it}^{\frac{\phi-1}{\phi}} + (1-\alpha) X_{it}^{\frac{\phi-1}{\phi}} \right)^{\frac{\phi}{\phi-1}} \right].$$

Here, $\overline{Y}_{it}$ is a given amount of output, and mc_{it} is the marginal cost (Lagrange-multiplier). Reorganizing the first-order conditions yields (3.8) and (3.9).

The pricing problem of the firm (3.10) can be written as:

$$\max_{\{P_{it+k}\}_{k=0}^{\infty}} \mathbb{E}_t \sum_{k=0}^{\infty} q_{t,t+k} \left\{ \frac{P_{it+k}}{P_{t+k}} Y_{it+k} - mc_{it+k} Y_{it+k} - Y_{it+k} \right\},$$

subject to (3.6) and (3.11). The first-order condition with respect to P_{it} equals

$$Y_{it}/P_t + \left(P_{it}/P_t - mc_{it} \right) \frac{\partial Y_{it}}{\partial P_{it}} - \frac{\partial Y_{it}}{\partial P_{it}} - \mathbb{E}_t \left[q_{t,t+1} \frac{\partial Y_{it+1}}{\partial P_{it}} \right] = 0.$$

Substituting, imposing symmetry, and rearranging yields the price Phillips curve (3.12).

B.1.4 Ramsey planner

The Lagrangian of the Ramsey planner in Section 5 is given by:

$$\begin{aligned}
\mathcal{L} = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t & \left[\frac{C_t^{1-\gamma}}{1-\gamma} - \frac{L_t^{1+\varphi}}{1+\varphi} + \mu_{1t} \left[C_t^{-\gamma} - \beta \mathbb{E}_t \left[C_{t+1}^{-\gamma} \frac{(1+i_t)}{\Pi_{t+1}} \right] \right] \right. \\
& + \mu_{2t} \left[C_t^{-\gamma} \left[(1+\tau_W)(\varepsilon_W - 1) w_t L_t + \gamma_W \left(\Pi_t^W - 1 \right) Y_t \Pi_t^W \right] \right. \\
& \left. - {L_t}^{\varphi+1} \varepsilon_W - \beta \mathbb{E}_t \left[C_{t+1}^{-\gamma} \gamma_W \left(\Pi_{t+1}^W - 1 \right) Y_{t+1} \Pi_{t+1}^W \right] \right] \\
& + \mu_{3t} \left[\frac{1}{\gamma_P} \left[(1+\tau_P)(1-\varepsilon) + \varepsilon m c_t \right] + \beta \mathbb{E}_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-\gamma} (\Pi_{t+1} - 1) \Pi_{t+1} \frac{Y_{t+1}}{Y_t} \right] - (\Pi_t - 1) \Pi_t \right] \\
& \left. + \mu_{4t} \left[\left[\frac{w_t}{\alpha m c_t} \right]^{-\phi} Y_t - L_t \right] + \mu_{5t} \left[\left[\frac{p_t^X}{m c_t (1-\alpha)} \right]^{-\phi} Y_t - X_t \right] + \mu_{6t} \left[Y_t - \mathrm{Y}_t^P - \mathrm{Y}_t^W - C_t \right] \right].
\end{aligned}$$

The pertaining first-order equations with respect to $i_t, C_t, L_t, \Pi_t, X_t, mc_t$, and w_t are

$$\begin{aligned}
\frac{\partial \mathcal{L}}{\partial i_t} &= \mu_{1t} \beta \mathbb{E}_t \left[\frac{C_{t+1}^{-\gamma}}{\Pi_{t+1}} \right] = 0, \qquad \Rightarrow \mu_{1t} = 0. \\
\frac{\partial \mathcal{L}}{\partial C_t} &= C_t^{-\gamma} + \mu_{2t-1} \left[\gamma C_t^{-\gamma-1} \gamma_W \left(\Pi_t^W - 1 \right) Y_t \Pi_t^W \right] - \mu_{2t} \left[\gamma C_t^{-\gamma-1} \left[(1+\tau_W)(\varepsilon_W - 1) w_t L_t + \gamma_W \left(\Pi_t^W - 1 \right) Y_t \Pi_t^W \right] \right] \\
&\quad - \mu_{3t-1} \left[\gamma (C_t)^{-\gamma-1} C_{t-1}^{\gamma} (\Pi_t - 1) \Pi_t \frac{Y_t}{Y_{t-1}} \right] + \mu_{3t} \left[\gamma C_t^{\gamma-1} \beta \mathbb{E}_t \left[(C_{t+1})^{-\gamma} (\Pi_{t+1} - 1) \Pi_{t+1} \frac{Y_{t+1}}{Y_t} \right] \right] - \mu_{6t} = 0, \\
\frac{\partial \mathcal{L}}{\partial L_t} &= -L_t^{\varphi} - \mu_{2t-1} \left[C_t^{-\gamma} \gamma_W \left(\Pi_t^W - 1 \right) Y_{Lt} \Pi_t^W \right] \\
&\quad + \mu_{2t} \left[C_t^{-\gamma} \left[(1+\tau_W)(\varepsilon_W - 1) w_t + \gamma_W \left(\Pi_t^W - 1 \right) Y_{Lt} \Pi_t^W \right] - (\varphi + 1) {L_t}^{\varphi} \varepsilon_W \right] \\
&\quad + \mu_{3t-1} \left[\left(\frac{C_t}{C_{t-1}} \right)^{-\gamma} (\Pi_t - 1) \Pi_t \frac{Y_{Lt}}{Y_{t-1}} \right] - \mu_{3t} \left[\beta \mathbb{E}_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-\gamma} (\Pi_{t+1} - 1) \Pi_{t+1} \frac{Y_{t+1}}{Y_t^2} Y_{Lt} \right] \right] \\
&\quad + \mu_{4t} \left[\left[\frac{w_t}{\alpha m c_t} \right]^{-\phi} Y_{Lt} - 1 \right] + \mu_{5t} \left[\left[\frac{p_t^X}{m c_t (1-\alpha)} \right]^{-\phi} Y_{Lt} \right] + \mu_{6t} \left[1 - \mathrm{Y}_{Yt}^P - \mathrm{Y}_{Yt}^W \right] Y_{Lt} = 0, \\
\frac{\partial \mathcal{L}}{\partial \Pi_t} &= (\mu_{2t} - \mu_{2t-1}) \left[C_t^{-\gamma} \gamma_W \left(2\Pi_t^W - 1 \right) Y_t \Pi_{\Pi t}^W \right] \\
&\quad + \mu_{3t-1} \left[\left(\frac{C_t}{C_{t-1}} \right)^{-\gamma} (2\Pi_t - 1) \frac{Y_t}{Y_{t-1}} \right] - \mu_{3t} \left[(2\Pi_t - 1) \right] - \mu_{6t} \left[\mathrm{Y}_{\Pi t}^P + \mathrm{Y}_{\Pi t}^W \right] = 0, \\
\frac{\partial \mathcal{L}}{\partial X_t} &= (\mu_{2t} - \mu_{2t-1}) \left[C_t^{-\gamma} \left[\gamma_W \left(\Pi_t^W - 1 \right) Y_{Xt} \Pi_t^W \right] \right] \\
&\quad + \mu_{3t-1} \left[\left(\frac{C_t}{C_{t-1}} \right)^{-\gamma} (\Pi_t - 1) \Pi_t \frac{Y_{Xt}}{Y_{t-1}} \right] - \mu_{3t} \left[\beta \mathbb{E}_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-\gamma} (\Pi_{t+1} - 1) \Pi_{t+1} \frac{Y_{t+1}}{Y_t^2} Y_{Xt} \right] \right] \\
&\quad + \mu_{4t} \left[\left[\frac{w_t}{\alpha m c_t} \right]^{-\phi} Y_{Xt} \right] + \mu_{5t} \left[\left[\frac{p_t^X}{m c_t (1-\alpha)} \right]^{-\phi} Y_{Xt} - 1 \right] + \mu_{6t} \left[1 - \mathrm{Y}_{Yt}^P - \mathrm{Y}_{Yt}^W \right] Y_{Xt} = 0,
\end{aligned}$$

$$
\begin{aligned}
\frac{\partial \mathcal{L}}{\partial mc_t} &= \mu_{3t}\left[\frac{\varepsilon}{\gamma_P}\right] + \mu_{4t}\left[\left[\frac{w_t}{\alpha}\right]^{-\phi}\phi mc_t^{\phi-1}Y_t\right] + \mu_{5t}\left[\left[\frac{p_t^X}{(1-\alpha)}\right]^{-\phi}\phi mc_t^{\phi-1}Y_t\right] = 0,\\
\frac{\partial \mathcal{L}}{\partial w_t} &= \mu_{2t}C_t^{-\gamma}\left(1+\tau_W\right)\left(\varepsilon_W-1\right)L_t + \left(\mu_{2t}-\mu_{2t-1}\right)\left[C_t^{-\gamma}\gamma_W\left(2\Pi_t^W-1\right)Y_t\Pi_{wt}^W\right]\\
&\quad + \beta\mathbb{E}_t\left[\left(\mu_{2t+1}-\mu_{2t}\right)\left[C_{t+1}^{-\gamma}\left[\gamma_W\left(2\Pi_{t+1}^W-1\right)Y_{t+1}\Pi_{wt+1}^W\right]\right]\right]\\
&\quad - \mu_{4t}\left[\phi w_t^{-1}\left[\frac{w_t}{\alpha mc_t}\right]^{-\phi}Y_t\right] - \mu_{6t}\left[\Upsilon_{wt}^W\right] - \beta\mathbb{E}_t\left[\mu_{6t+1}\Upsilon_{wt+1}^W\right] = 0.
\end{aligned}
$$

The above derivatives are defined below

$$
\begin{aligned}
\Pi_{wt}^W &= \Pi_t/w_{t-1},\\
\Pi_{\Pi t}^W &= w_t/w_{t-1},\\
\Pi_{wt+1}^W &= -\Pi_{t+1}w_{t+1}/w_t^2,\\
Y_{Xt} &= \frac{(1-\alpha)\,Y_t/X_t}{\alpha\left(L_t/X_t\right)^{\frac{\phi-1}{\phi}}+(1-\alpha)},\\
Y_{Lt} &= \frac{\alpha Y_t/L_t}{\alpha+(1-\alpha)\left(X_t/L_t\right)^{\frac{\phi-1}{\phi}}},\\
\Upsilon_{Yt}^P &= \frac{\gamma_P}{2}\left(\Pi_t-1\right)^2,\\
\Upsilon_{\Pi t}^P &= \gamma_P\left(\Pi_t-1\right)Y_t,\\
\Upsilon_{Yt}^W &= \frac{\gamma_W}{2}\left(\Pi_t^W-1\right)^2,\\
\Upsilon_{\Pi t}^W &= \gamma_W\left(\Pi_t\frac{w_t}{w_{t-1}}-1\right)Y_tw_t/w_{t-1},\\
\Upsilon_{wt}^W &= \gamma_W\left(\Pi_tw_t/w_{t-1}-1\right)\Pi_tY_t/w_{t-1},\\
\Upsilon_{wt+1}^W &= -\gamma_W\left(\Pi_{t+1}w_{t+1}/w_t-1\right)\Pi_{t+1}Y_{t+1}w_{t+1}/w_t^2.
\end{aligned}
$$

B.1.5 Proof of proposition 1

Proof. To prove Proposition 1, we start from firm i's labor demand

$$
L_{it} = \left[\frac{w_t}{\alpha mc_{it}}\right]^{-\phi}Y_{it},
$$

which yields the marginal cost function

$$
mc_{it} = \frac{w_t}{\alpha}\left(\frac{L_{it}}{Y_{it}}\right)^{1/\phi}.
$$

Inserting the production function (3.7) and re-arranging yields:

$$mc_{it} = \frac{w_t}{\alpha}\left(\alpha + (1-\alpha)\left(\frac{L_{it}}{X_{it}}\right)^{\frac{1-\phi}{\phi}}\right)^{\frac{1}{1-\phi}}.$$

From this expression, we obtain:

$$\lim_{\phi \to 0} mc_{it} = \begin{cases} \frac{w_t}{\alpha} & \text{if } X_{it} = L_{it} \\ w_t & \text{if } X_{it} > L_{it}, \\ \infty & \text{if } X_{it} < L_{it}. \end{cases}$$

■

Regressor:	Increase	Decrease
Regressand:	Subseq. decrease	Subseq. increase
	$\phi = 0.003$	
$\hat{\beta}_1$	1.00^{***} (0.03)	0.08^{*} (0.05)
R^2	0.81	0.01
n	344	344
	$\phi = 0.02$	
$\hat{\beta}_1$	0.66^{***} (0.04)	0.23^{***} (0.05)
R^2	0.40	0.06
n	347	347
	$\phi = 0.12$	
$\hat{\beta}_1$	0.45^{***} (0.05)	0.42^{***} (0.05)
R^2	0.19	0.19
n	343	343

Table B.1. Robustness of the inflation plucking property. This table reports OLS regression results for three alternative calibrations of ϕ. The baseline calibration sets $\phi = 0.003$, while $\phi = 0.02$ is the mean estimate reported by Hassler, Krusell, and Olovsson (2021). The remaining parameters are set to their baseline values shown in Table 3.1. The results are based on three 5400-quarter simulations of the nonlinear model, each using the same realizations of monetary and supply shocks. The hyperparameter used to identify peaks and troughs is chosen to yield approximately the same number of observations in each model regression as in the corresponding OECD regressions reported in Table 2.1. Standard errors are reported in parentheses. The asterisks *** and * denote significance at the 1 and 10 percent levels, respectively.

B.2 Robustness: Elasticity of substitution

Table B.1 shows the relationship between amplitudes of inflation increases and decreases in model-generated data for different values of the elasticity of substitution, ϕ. Under the baseline calibration, $\phi = 0.003$, the nonlinear model generates pronounced inflation plucking cycles.[25] Increasing the elasticity to $\phi = 0.02$, corresponding to the mean estimate reported by Hassler, Krusell, and Olovsson (2021), weakens the asymmetry, although evidence of plucking cycles remains. By contrast, when $\phi = 0.12$, the model no longer generates inflation plucking cycles. These findings demonstrate that the nonlinear model's ability to replicate the inflation plucking cycles observed in the data depends critically on the empirically plausible assumption that ϕ is close to zero.

[25] The regression results for $\phi = 0.003$ in Table B.1 correspond to those reported in Table 4.1.

B.3 Global solution algorithm

We define the grid of state variables, $w_{t-1} \in \boldsymbol{w} \equiv [w_{min}, \ldots, w_{max}]^{\intercal}$, $X_t \in \boldsymbol{X} \equiv [X_{min}, \ldots, X_{max}]^{\intercal}$, and $\varepsilon_t^i \in \boldsymbol{\varepsilon^i} = \left[\varepsilon_{min}^i, \ldots, \varepsilon_{max}^i\right]^{\intercal}$ and create a column vector containing all shock combinations, that is, $z_t \in \boldsymbol{z} \equiv \text{vec}(\boldsymbol{\varepsilon^i}^{\intercal}\boldsymbol{X})$. The corresponding transition matrix for z_t is $\Pi = \Pi_X \otimes \Pi_{\varepsilon^i}$ where Π_X and Π_{ε^i} are transition matrices. We discretize each exogenous shock into eleven realizations and wages into a grid of 801 points.

Let $L_t\left(\boldsymbol{w}\boldsymbol{z}^{\intercal}\right), \Pi_t\left(\boldsymbol{w}\boldsymbol{z}^{\intercal}\right)$, and $\Pi_t^W\left(\boldsymbol{w}\boldsymbol{z}^{\intercal}\right)$ be matrices of dimension 801×121 and suppose we have an initial guess on these matrices. The algorithm works as follows:

1. Given our current estimates, we obtain (using elementwise multiplication $\circ$)

$$w_t\left(\boldsymbol{w}\boldsymbol{z}^{\intercal}\right) = \Pi_t^W\left(\boldsymbol{w}\boldsymbol{z}^{\intercal}\right) \circ \Pi_t\left(\boldsymbol{w}\boldsymbol{z}^{\intercal}\right)^{-1} \circ \boldsymbol{w},$$

   which allows us to obtain estimates on

$$L_{t+1}\left(\boldsymbol{w}\boldsymbol{z}^{\intercal}\right), \Pi_{t+1}\left(\boldsymbol{w}\boldsymbol{z}^{\intercal}\right), \Pi_{t+1}^W\left(\boldsymbol{w}\boldsymbol{z}^{\intercal}\right),$$

   using interpolation.

2. Using (3.7), we obtain $Y_t\left(\boldsymbol{w}\boldsymbol{z}^{\intercal}\right)$ and $Y_{t+1}\left(\boldsymbol{w}\boldsymbol{z}^{\intercal}\right)$.

3. Using (3.14), we obtain $C_t\left(\boldsymbol{w}\boldsymbol{z}^{\intercal}\right)$ and $C_{t+1}\left(\boldsymbol{w}\boldsymbol{z}^{\intercal}\right)$.

4. From the intermediate goods Phillips curve (3.12), we get the marginal costs

$$\begin{aligned} mc_t\left(\boldsymbol{w}\boldsymbol{z}^{\intercal}\right) = 1 + \tau_P - \frac{1}{\varepsilon}\left[1 + \tau_P - \gamma_P\left(\Pi_t\left(\boldsymbol{w}\boldsymbol{z}^{\intercal}\right) - 1\right) \circ \Pi_t\left(\boldsymbol{w}\boldsymbol{z}^{\intercal}\right)\right] \\ - \frac{1}{\varepsilon}\gamma_P\beta\left[C_t\left(\boldsymbol{w}\boldsymbol{z}^{\intercal}\right)\right]^{\gamma} \circ \left[Y_t\left(\boldsymbol{w}\boldsymbol{z}^{\intercal}\right)\right]^{-1} \\ \circ \left[\left(C_{t+1}\right)^{-\gamma} \circ \left(\Pi_{t+1}\left(\boldsymbol{w}\boldsymbol{z}^{\intercal}\right) - 1\right) \circ \Pi_{t+1}\left(\boldsymbol{w}\boldsymbol{z}^{\intercal}\right) \circ Y_{t+1}\left(\boldsymbol{w}\boldsymbol{z}^{\intercal}\right)\Pi^{\intercal}\right], \end{aligned}$$

5. From the non-labor demand of intermediate firms (3.9), we obtain its price

$$p_t^X\left(\boldsymbol{w}\boldsymbol{z}^{\intercal}\right) = (1-\alpha)\left[X_t\left(\boldsymbol{w}\boldsymbol{z}^{\intercal}\right) \circ \left[Y_t\left(\boldsymbol{w}\boldsymbol{z}^{\intercal}\right)\right]^{-1}\right]^{\frac{-1}{\phi}} \circ mc_t\left(\boldsymbol{w}\boldsymbol{z}^{\intercal}\right).$$

6. Lastly, we can update our policy functions

   a. Combining the Euler equation of consumption (3.3) with the Taylor rule (3.13) solves for

$$\begin{aligned} \Pi_t^n\left(\boldsymbol{w}\boldsymbol{z}^{\intercal}\right) = \left[\left(C_t\left(\boldsymbol{w}\boldsymbol{z}^{\intercal}\right)\right)^{\gamma}(1+i) \circ \left\{1 + \varepsilon_t^i\left(\boldsymbol{w}\boldsymbol{z}^{\intercal}\right)\right\} \circ \left(\hat{Y}_t\left(\boldsymbol{w}\boldsymbol{z}^{\intercal}\right)\right)^{\mu_Y}\right. \\ \left. \circ\beta\left[\left(C_{t+1}\left(\boldsymbol{w}\boldsymbol{z}^{\intercal}\right)\right)^{-\gamma} \circ \Pi_{t+1}\left(\boldsymbol{w}\boldsymbol{z}^{\intercal}\right)^{-1}\right]\Pi^{\intercal}\right]^{\frac{-1}{\mu_\Pi}}. \end{aligned}$$

Note that the flexible price output (used in the output gap, $\hat{Y}_t(\boldsymbol{w}\boldsymbol{z}^\intercal)$), is computed using this algorithm with γ_P and γ_W set to zero.

b. Using firm demand for labor (3.8), we get

$$L_t^n(\boldsymbol{w}\boldsymbol{z}^\intercal) = \left[\alpha^{-1} w_t(\boldsymbol{w}\boldsymbol{z}^\intercal) \circ [mc_t(\boldsymbol{w}\boldsymbol{z}^\intercal)]^{-1}\right]^{-\phi} \circ Y_t(\boldsymbol{w}\boldsymbol{z}^\intercal).$$

c. Lastly, using the wage Phillips curve (3.4), we can solve for

$$\Pi_t^{Wn}(\boldsymbol{w}\boldsymbol{z}^\intercal) = [2\mathbb{C}_1]^{-1} \circ \left[-\mathbb{C}_2 \pm \left[[\mathbb{C}_2]^2 - 4\mathbb{C}_1 \circ \mathbb{C}_3\right]^{0.5}\right],$$

with

$$\begin{aligned}
\mathbb{C}_1 &= \gamma_W [C_t(\boldsymbol{w}\boldsymbol{z}^\intercal)]^{-\gamma} \circ Y_t(\boldsymbol{w}\boldsymbol{z}^\intercal), \\
\mathbb{C}_2 &= -\mathbb{C}_1, \\
\mathbb{C}_3 &= (1+\tau_W)(\varepsilon_W - 1)[C_t(\boldsymbol{w}\boldsymbol{z}^\intercal)]^{-\gamma} \circ w_t(\boldsymbol{w}\boldsymbol{z}^\intercal) \circ L_t(\boldsymbol{w}\boldsymbol{z}^\intercal) - \varepsilon_W [L_t(\boldsymbol{w}\boldsymbol{z}^\intercal)]^{\varphi+1} \\
&\quad - \gamma_W \beta \left[[C_{t+1}(\boldsymbol{w}\boldsymbol{z}^\intercal)]^{-\gamma} \circ \left[\Pi_{t+1}^W(\boldsymbol{w}\boldsymbol{z}^\intercal) - 1\right] \circ Y_{t+1}(\boldsymbol{w}\boldsymbol{z}^\intercal) \circ \Pi_{t+1}^W(\boldsymbol{w}\boldsymbol{z}^\intercal)\right] \Pi^\intercal.
\end{aligned}$$

The wage Phillips curve yields two candidate roots for $\Pi_{W,t}$. We select the economically relevant branch by choosing the admissible root closest to the steady-state value, $\Pi_W = 1$. This selects the branch that is locally continuous with the deterministic steady state.

7. If

$$\begin{bmatrix} \left\|\text{vec}\left(\Pi_t^{Wn}(\boldsymbol{w}\boldsymbol{z}^\intercal)\right) - \text{vec}\left(\Pi_t^W(\boldsymbol{w}\boldsymbol{z}^\intercal)\right)\right\|_\infty \\ \left\|\text{vec}\left(\Pi_t^n(\boldsymbol{w}\boldsymbol{z}^\intercal)\right) - \text{vec}\left(\Pi_t(\boldsymbol{w}\boldsymbol{z}^\intercal)\right)\right\|_\infty \\ \left\|\text{vec}\left(L_t^n(\boldsymbol{w}\boldsymbol{z}^\intercal)\right) - \text{vec}\left(L_t(\boldsymbol{w}\boldsymbol{z}^\intercal)\right)\right\|_\infty \end{bmatrix} < \boldsymbol{\epsilon},$$

then stop. If the conditions are not met, revise the policy functions as follows:

$$\omega \begin{bmatrix} \Pi_t^{Wn}(\boldsymbol{w}\boldsymbol{z}^\intercal) \\ \Pi_t^n(\boldsymbol{w}\boldsymbol{z}^\intercal) \\ L_t^n(\boldsymbol{w}\boldsymbol{z}^\intercal) \end{bmatrix} + (1-\omega) \begin{bmatrix} \Pi_t^W(\boldsymbol{w}\boldsymbol{z}^\intercal) \\ \Pi_t(\boldsymbol{w}\boldsymbol{z}^\intercal) \\ L_t(\boldsymbol{w}\boldsymbol{z}^\intercal) \end{bmatrix}.$$

with $\omega \in (0,1)$ and return to step 1.

B.4 Accuracy of perturbation

To assess the accuracy of the perturbation approximations, we propose the following metric:

$$\Xi\left(w, X, \varepsilon^i\right) = 100 \times \left| \frac{V^{pa}\left(w, X, \varepsilon^i\right) - V\left(w, X, \varepsilon^i\right)}{V\left(w, X, \varepsilon^i\right)} \right|,$$

where V^{pa} is a perturbation approximation of the lifetime utility, and V is its exact value from the global solution. Intuitively, Ξ has the interpretation of percentage deviations from the true welfare.

Table B.2 summarizes the error measures for rising orders of perturbation approximations. As the order rises, the mean and max approximation errors strictly decline.

Perturbation	First order	Second order	Third order	Fourth order	Fifth order
$\mathbb{E}(\Xi)$	0.0437	0.0210	0.0205	0.0061	0.0059
Max(Ξ)	0.0600	0.0298	0.0281	0.0257	0.0159

Table B.2. Accuracy of perturbation. This table reports various accuracy measures for perturbation of increasing order using the lifetime utility. We use the ergodic distribution of the global solution to evaluate the errors.

Figure B.1 shows the impulse responses of four key variables from the model to a large negative supply shock. The impulse responses are computed using a first-order approximation, a fifth-order approximation, and the exact (global) solution, respectively. As shown in Figure B.1, the fifth-order approximation is highly accurate, even for large shocks.

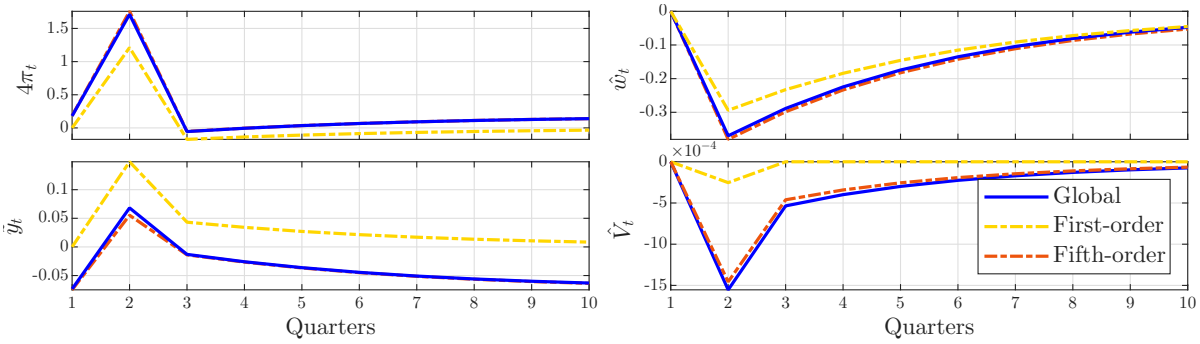


Figure B.1. Impulse response functions. Impulse responses to a large negative supply shock using a global (blue), Dynare's first-order (yellow), and fifth-order (red) solution, respectively. Hatted variables are denoted in percentage deviations from the risky steady state.

References

AUERBACH, A. J. AND Y. GORODNICHENKO (2012): "Measuring the Output Responses to Fiscal Policy," *American Economic Journal: Economic Policy*, 4, 1–27. (Cited on page 4.)

BABB, N. R. AND A. K. DETMEISTER (2017): "Nonlinearities in the Phillips Curve for the United States: Evidence Using Metropolitan Data," Tech. Rep. 2017-070, Board of Governors of the Federal Reserve System, accessed: 2025-02-24. (Cited on page 4.)

BALLEER, A. AND M. NOELLER (2024): "Monetary policy in the presence of supply constraints: Evidence from German firm-level data," CEPR Discussion Paper 18732, CEPR Press, Paris & London. (Cited on page 11.)

BAQAEE, D. R. AND E. FARHI (2019): "The Macroeconomic Impact of Microeconomic Shocks: Beyond Hulten's Theorem," *Econometrica*, 87, 1155–1203. (Cited on page 4.)

BARNICHON, R., D. DEBORTOLI, AND C. MATTHES (2022): "Understanding the Size of the Government Spending Multiplier: It's in the Sign," *The Review of Economic Studies*, 89, 87–117. (Cited on page 4.)

BARNICHON, R. AND C. MATTHES (2018): "Functional Approximation of Impulse Responses," *Journal of Monetary Economics*, 99, 41–55. (Cited on pages 1, 8, 9, 10, 11, and 36.)

BASU, S. AND B. BUNDICK (2017): "Uncertainty Shocks in a Model of Effective Demand," *Econometrica*, 85, 937–958. (Cited on page 13.)

BENIGNO, P. AND G. B. EGGERTSSON (2024): "The Slanted-L Phillips Curve," *AEA Papers and Proceedings*, 114, 84–89. (Cited on page 4.)

BLANCO, A., C. BOAR, C. J. JONES, AND V. MIDRIGAN (2024): "Nonlinear Inflation Dynamics in Menu Cost Economies," Working Paper 32094, National Bureau of Economic Research. (Cited on page 4.)

BOECK, M., A. GRIMAUD, AND F. ZANETTI (2026): "Unemployment Plucking and the Phillips Curve." Mimeo. (Cited on page 4.)

BOEHM, C. E. AND N. PANDALAI-NAYAR (2022): "Convex Supply Curves," *American Economic Review*, 112, 3941–69. (Cited on page 4.)

BUNN, P., L. ANAYI, N. BLOOM, P. MIZEN, G. THWAITES, AND I. YOTZOV (2025): "How curvy is the Phillips curve?" Bank of England working papers 1107, Bank of England. (Cited on page 4.)

CALDARA, D., M. IACOVIELLO, AND D. YU (2026): "Measuring Shortages since 1900," Working paper. (Cited on pages 2, 9, 11, and 28.)

CERRATO, A. AND G. GITTI (2025): "The Return of the Phillips Curve: Evidence from US Cities," Working paper. (Cited on page 4.)

CHOI, J., T. DOH, A. FOERSTER, AND Z. MARTINEZ (2022): "Monetary Policy Stance Is Tighter than Federal Funds Rate," *FRBSF Economic Letter*, 2022, 1–5. (Cited on page 9.)

COLEMAN, W. J. (1989): "An algorithm to solve dynamic models," International Finance Discussion Papers 351, Board of Governors of the Federal Reserve System (U.S.). (Cited on page 15.)

——— (1990): "Solving the Stochastic Growth Model by Policy-Function Iteration," *Journal of Business & Economic Statistics*, 8, 27–29. (Cited on page 15.)

COLOMBO, D. AND F. TONI (2025): "Gas Prices and the Macroeconomy," Working paper. (Cited on page 16.)

COMIN, D. A., R. C. JOHNSON, AND C. J. JONES (2023): "Supply Chain Constraints and Inflation," Working Paper 31179, National Bureau of Economic Research. (Cited on page 4.)

DE POLIS, A., L. MELOSI, AND I. PETRELLA (2024): "The Taming of the Skew: Asymmetric Inflation Risk and Monetary Policy," CEPR Discussion Paper DP19760, Centre for Economic Policy Research. (Cited on page 4.)

DEBORTOLI, D., M. FORNI, L. GAMBETTI, AND L. SALA (2025): "Nonlinear Monetary Policy Tradeoffs," *Economic Journal*, forthcoming. (Cited on page 4.)

DUPRAZ, S., E. NAKAMURA, AND J. STEINSSON (2025): "A Plucking Model of Business Cycles," *Journal of Monetary Economics*, 152. (Cited on pages 2, 4, 5, and 11.)

ERCEG, C. J., D. W. HENDERSON, AND A. T. LEVIN (2000): "Optimal monetary policy with staggered wage and price contracts," *Journal of Monetary Economics*, 46, 281–313. (Cited on pages 12, 15, and 16.)

FORBES, K., J. GAGNON, AND C. G. COLLINS (2022): "Low Inflation Bends the Phillips Curve around the World," *Economia*, 45, 52–72. (Cited on page 4.)

FRIEDMAN, M. (1964): "Monetary studies of the national bureau," *The National Bureau Enters Its 45th Year*, 44, 7–25. (Cited on pages 1, 2, 3, and 4.)

——— (1993): "The "Plucking Model" of Business Fluctuations Revisited," *Economic Inquiry*, 31, 171–177. (Cited on pages 2 and 3.)

GAGLIARDONE, L. AND M. GERTLER (2026): "Oil Prices, Monetary Policy and Inflation Surges," *American Economic Journal: Macroeconomics*, forthcoming. (Cited on pages 4 and 16.)

GALÍ, J. (2015): *Monetary Policy, Inflation, and the Business Cycle: An Introduction to the New Keynesian Framework and Its Applications. Second edition*, no. 10495 in Economics Books, Princeton University Press. (Cited on pages 3, 16, and 24.)

GOLOSOV, M. AND R. LUCAS (2007): "Menu Costs and Phillips Curves," *Journal of Political Economy*, 115, 171–199. (Cited on page 4.)

HAMILTON, J. D. (2017): "Why You Should Never Use the Hodrick-Prescott Filter," NBER Working Papers 23429, National Bureau of Economic Research, Inc. (Cited on pages 8 and 34.)

HARDING, M., J. LINDÉ, AND M. TRABANDT (2023): "Understanding post-COVID inflation dynamics," *Journal of Monetary Economics*, 140, 101–118. (Cited on page 4.)

HARTLEY, J. S. (2021): "Friedman's plucking model: New international evidence from Maddison Project data," *Economics Letters*, 199, 109724. (Cited on page 4.)

HASSLER, J., P. KRUSELL, AND C. OLOVSSON (2021): "Directed Technical Change as a Response to Natural Resource Scarcity," *Journal of Political Economy*, 129, 3039–3072. (Cited on pages 15, 16, and 42.)

INTERNATIONAL MONETARY FUND (2022): "Wage Dynamics Post–COVID-19 and Wage-Price Spiral Risks," World Economic Outlook: Countering the Cost-of-Living Crisis, Chapter 2, International Monetary Fund. (Cited on page 20.)

JORDA, O. (2005): "Estimation and Inference of Impulse Responses by Local Projections," *American Economic Review*, 95, 161–182. (Cited on page 8.)

——— (2023): "Local Projections for Applied Economics," *Annual Review of Economics*, 15, 607–631. (Cited on page 8.)

KARADI, P., A. NAKOV, G. NUÑO, E. PASTÉN, AND D. THALER (2024): "Strike While the Iron Is Hot: Optimal Monetary Policy with a Nonlinear Phillips Curve," Discussion Paper 19339, Centre for Economic Policy Research, accessed from CEPR Discussion Papers series. (Cited on page 4.)

KIM, C.-J. AND C. R. NELSON (1999): "Friedman's Plucking Model of Business Fluctuations: Tests and Estimates of Permanent and Transitory Components," *Journal of Money, Credit and Banking*, 31, 317–334. (Cited on page 4.)

KOHLSCHEEN, E., R. MOESSNER, AND D. M. REES (2024): "The shape of business cycles: A cross-country analysis of Friedman's plucking theory," *Kyklos*, 77, 351–370. (Cited on page 4.)

LORENZONI, G. AND I. WERNING (2023): "Wage-Price Spirals," *Brookings Papers on Economic Activity*, Fall 2023. (Cited on page 4.)

LUCAS, R. (1987): "Models of business cycles," *Oxford: Blackwell*. (Cited on pages 3 and 26.)

——— (2003): "Macroeconomic Priorities," *American Economic Review*, 93, 1–14. (Cited on pages 3 and 26.)

NAKAMURA, E. AND J. STEINSSON (2008): "Five Facts about Prices: A Reevaluation of Menu Cost Models," *The Quarterly Journal of Economics*, 123, 1415–1464. (Cited on page 16.)

PHILLIPS, A. W. (1958): "The Relation Between Unemployment and the Rate of Change of Money Wage Rates in the United Kingdom, 1861–1957," *Economica*, 25, 283–299. (Cited on page 4.)

RAMEY, V. A. (2012): "Comment on "Roads to Prosperity or Bridges to Nowhere? Theory and Evidence on the Impact of Public Infrastructure Investment"," *NBER Macroeconomics Annual*, 27, 147–153. (Cited on page 8.)

ROTEMBERG, J. (1982): "Monopolistic Price Adjustment and Aggregate Output," *The Review of Economic Studies*, 49, 517–531. (Cited on page 14.)

ROUWENHORST, K. (1995): *Frontiers of business cycle research / Thomas F. Cooley, editor.*, Princeton University Press. (Cited on page 15.)

SINCLAIR, T. M. (2010): "Asymmetry in the Business Cycle: Friedman's Plucking Model with Correlated Innovations," *Studies in Nonlinear Dynamics and Econometrics*, 14, 1–31. (Cited on page 4.)

TAYLOR, J. B. (1993): "Discretion versus policy rules in practice," *Carnegie-Rochester Conference Series on Public Policy*, 39, 195–214. (Cited on pages 15 and 16.)

TENREYRO, S. AND G. THWAITES (2016): "Pushing on a String: U.S. Monetary Policy Is Less Powerful in Recessions," *American Economic Journal: Macroeconomics*, 8, 43–74. (Cited on page 4.)

UHLIG, H. (2005): "What are the effects of monetary policy on output? Results from an agnostic identification procedure," *Journal of Monetary Economics*, 52, 381–419. (Cited on page 9.)