Inflation Plucking Cycles*

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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. In contrast, 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 the observed plucking-cycle behavior. The fully nonlinear version of a standard New Keynesian model, extended with a scarce non-labor input with low substitutability in production, 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 more aggressively to large negative supply shocks. This policy dampens the inflation plucking cycles, reduces the inflation bias, and raises the average output level, yielding substantial welfare gains.

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

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

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1. Introduction

This paper documents a new empirical fact about inflation dynamics in advanced economies, namely that inflation displays "plucking cycles": 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 33 out of 38 OECD countries, including the US.

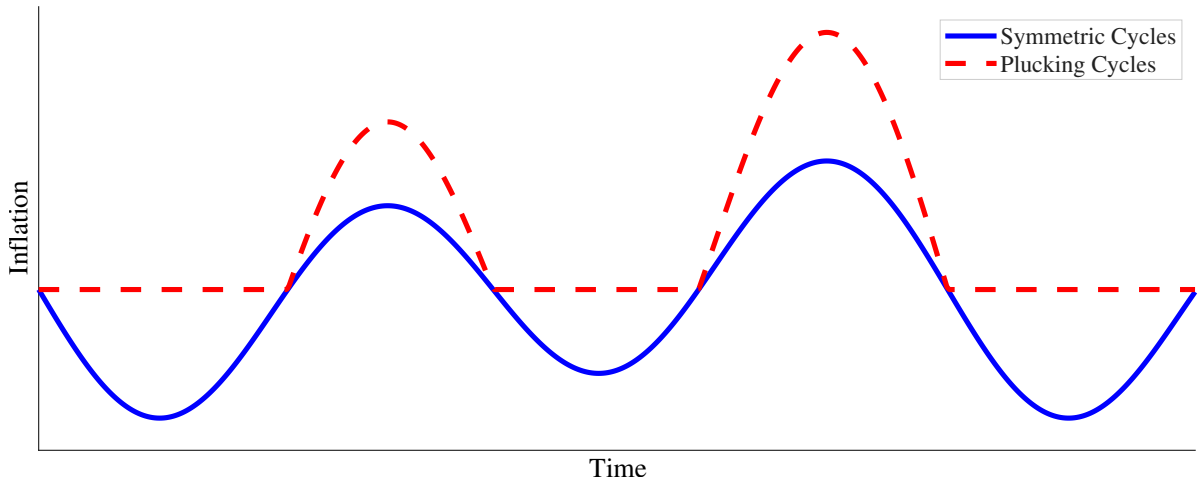


Figure 1.1. Inflation cycles: Symmetric versus plucking.

To help 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, whereas contractionary monetary policy shocks lead to relatively small reductions in inflation. Second, we find that negative supply shocks generate relatively large inflation increases, whereas positive supply shocks generate relatively small inflation reductions. Taken together, these findings imply that both monetary policy

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

shocks and supply shocks give rise to right-skewed inflation plucking cycles similar to those we observe in the OECD data.

To account for our empirical findings, 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 plucking property. The model can also account for the asymmetric inflation responses to monetary policy shocks and supply shocks observed 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). Due to its limited substitutability, a large negative shock to the supply of the non-labor input will disproportionally raise firms' marginal costs, leading to an inflation surge. In contrast, a large positive supply shock will not generate large disinflationary pressures, as marginal costs remain nearly constant in response to the shock. Similarly, a large expansionary monetary policy shock will trigger supply constraints and lead to an inflation burst, while a contractionary monetary shock will lead to a muted inflation response.[2] The asymmetric response of marginal costs to both monetary policy shocks and supply shocks generate inflation plucking cycles as seen in the data.

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

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

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 sizable 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.[3] Our econometric evidence (and our theoretical model) implies that both supply shocks and monetary policy shocks generate left-skewed plucking cycles in output, consistent with Friedman's hypothesis and the empirical findings in Dupraz, Nakamura, and Steinsson (2025).

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

[3]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.

by our model.[4] 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 (2024) 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.

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), which gives rise to an S-shaped Phillips curve.[5] 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. Similarly to our paper, these authors find that optimal monetary policy should account for asymmetric inflation risk.

Other models can potentially help explain the inflation plucking cycles we observe in the data. These include models of downward nominal wage rigidity (e.g., Benigno and Eggertsson, 2024, Dupraz, Nakamura, and Steinsson, 2025), non-linear demand curves (e.g., Harding, Lindé, and Trabandt, 2023), and state-dependent pricing coupled with positive trend inflation (e.g., Bunn et al., 2025, Karadi et al., 2024). Further exploring the underlying drivers of inflation plucking cycles is an interesting avenue for future research.

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 evidence on the asymmetric responses of inflation to macroeconomics 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.

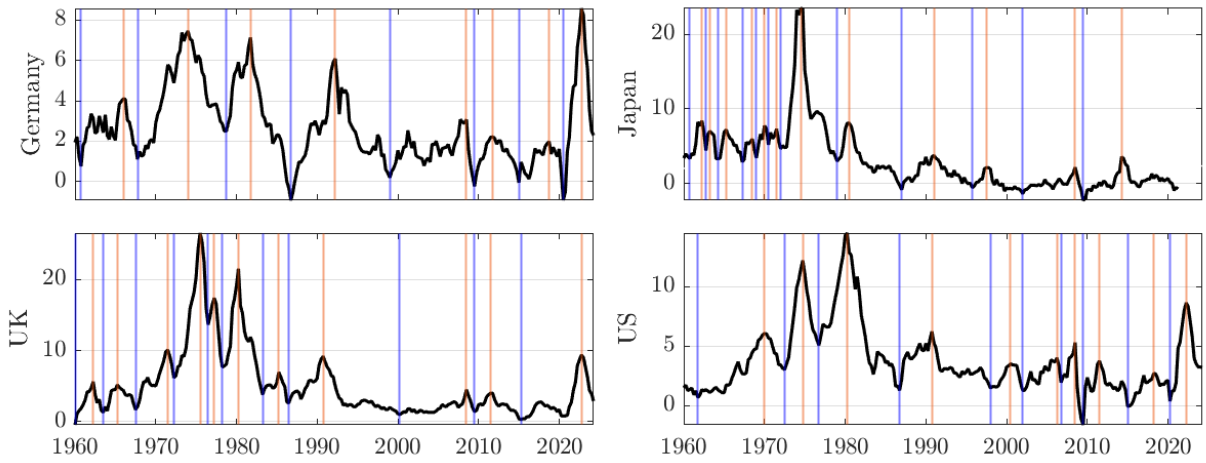


Figure 2.1. Inflation peaks and troughs. This figure displays quarterly data on inflation from 1960Q1 to 2024Q2, along with marked peaks of inflation (red) and troughs (blue) for Germany, Japan, the United Kingdom, and the United States.

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.[6]

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 be considered a peak, or decrease by at least the same amount from the previous peak to be considered a trough.[7]

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

[4]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.

[5]Ghassibe and Nakov (2025) study the role of networks in the Golosov and Lucas (2007) model.

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

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

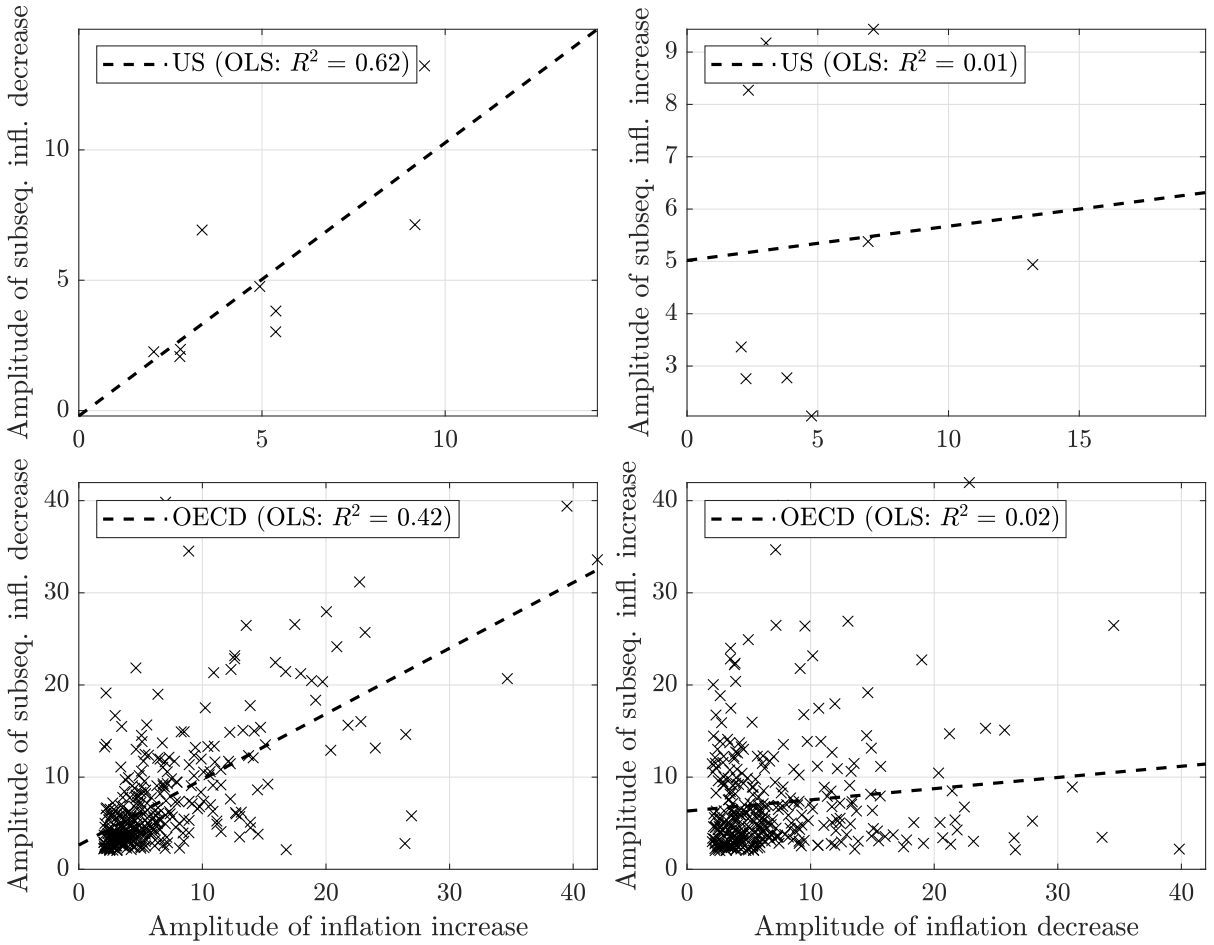


Figure 2.2. Inflation plucking cycles. This figure displays scatter plots of amplitudes of inflation cycles in US data (upper panels) and cross-country pooled OECD data (lower panels). The dashed lines are univariate OLS regression lines. The left panels show amplitudes of inflation increases versus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

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 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 statistical 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,

	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.

increases in inflation forecast subsequent reductions nearly one-for-one. 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.[8] 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.[9] The country-specific results are shown in Tables A.2 and A.3 in Appendix A.[10] 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 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 plucking-cycle behavior documented in the previous section. Specifically, we show

[8] 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.

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

[10] In the country-specific regressions, we use all available data.

that both types of shocks give rise to right-skewed plucking cycles in inflation. We also show that both types of shocks give rise to left-skewed plucking cycles in output, consistent with Friedman's plucking model and the empirical findings in Dupraz, Nakamura, and Steinsson (2025).

For this purpose, we rely on the econometric technique, Functional Approximations of Impulse Responses (FAIR), 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 (VARs) 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) shows 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 estimated. Each of these parameters captures a specific feature of the IRF, 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:

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

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 trivariate model on US data covering the period from 1960:Q1 to 2024:Q2. The model includes (log) real GDP, CPI inflation and the policy interest rate. For the latter, we use data on the "proxy federal funds rate" constructed by Choi et al. (2022), which is available for the period 1976:Q3-2024:Q2, and the actual federal funds rate for the preceding period. The proxy federal funds rate captures the broader stance of monetary policy, mitigating the limitations imposed by the zero lower bound.[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 only shock that raises the interest rate but lowers both output and inflation. For supply shocks, we assume that a negative supply shock is the only shock that lowers output but raises both inflation and the interest rate. 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.[12] 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.

[11] Barnichon and Matthes (2018) obtain similar results for monetary policy shocks for a sample that ends in 2007:Q4, before the onset of the first ZLB episode. We have verified that our results are robust to excluding the ZLB periods.

[12] Barnichon and Matthes (2018) use two Gaussian basis functions to approximate the inflation impulse response to monetary policy shocks but obtain similar results.

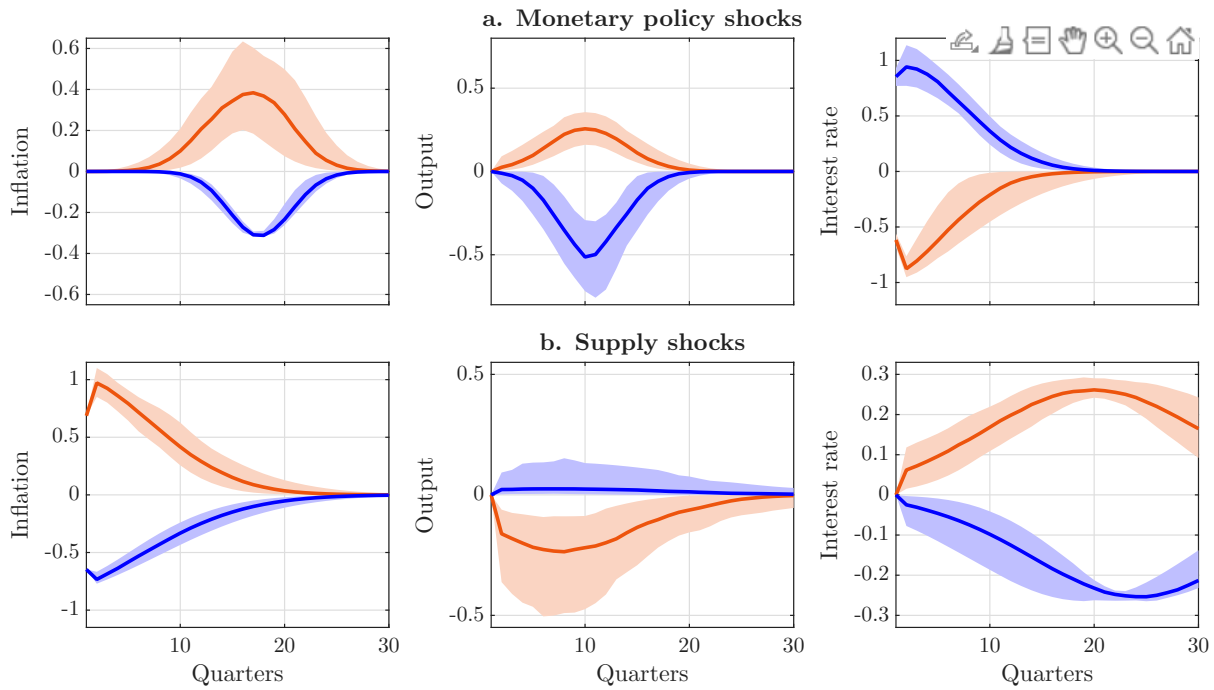


Figure 2.3. Impulse responses. This figure contains impulse responses to one-standard-deviation expansionary (red) versus contractionary (blue) monetary policy shocks (panel a) and positive (blue) versus negative (red) supply shocks (panel b) in U.S. data. Shaded bands denote the 5th and 95th posterior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

2.2.3 Results

Figure 2.3 displays our econometric results. The upper panel contains the impulse responses to contractionary versus expansionary monetary policy shocks, and the lower panel shows 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, in response to a negative supply shock, inflation displays a relatively large increase and output displays a relatively large decline. Conversely, a positive supply shock generates a weaker response in both variables.

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 and left-skewed plucking cycles in output, consistent with Friedman's plucking model and the empirical evidence in Dupraz, Nakamura, and Steinsson (2025).[13] In the following section, we

[13] Barnichon and Matthes (2018) obtain similar results for monetary policy shocks using the unem-

propose a structural model that can account for these 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, which we solve with global methods. In the model, a continuum of monopolistically competitive households, each supplying a differentiated labor service, maximizing their lifetime utility, and setting 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:

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

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 de-

ployment rate as a measure of economic activity. We have verified that our results are robust to using the unemployment rate instead of log(GDP).

mand 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).[14]

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

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

producer for the i-th intermediate good is given by

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

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 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 $\{P_{it}\}_{t=0}^{\infty}$ to maximize an infinite horizon of discounted profits:

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

where $q_{t,t+j} = \beta^j \left(C_{t+j}/C_t\right)^{-\gamma}$ 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:

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

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:

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

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: $T_t = \tau_p Y_t + \tau_W w_t L_t$.

3.4 Market clearing

The goods market clearing condition is given by:

$$Y_t = C_t + Y_t^P + Y_t^W. \quad (3.14)$$

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 a seven-state Markov chain. The details of the solution algorithm are laid out in Appendix B.2.

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, to 2 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

Parameters		Value	Source/Target
	Households		
β	Subjective discount factor	0.99	4% s.s. real interest rate
γ	Coefficient of relative risk aversion	2	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	0.005	Impulse responses (Figure 2.3)
α	CES share parameter	0.9	2% s.s. non-labor cost share
	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	0.0048	Impulse responses (Figure 2.3)
σ_i	Standard deviation, monetary policy shock	0.0050	Impulse responses (Figure 2.3)

Table 3.1. Calibration.

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 an average price duration of three quarters in the linearized version of the model. This value is, in turn, consistent with the microeconometric evidence in Nakamura and Steinsson (2008). We set the elasticity of substitution with respect to intermediate goods to $\varepsilon = 6$, which is a standard value. The elasticity of substitution between labor and the non-labor production input, ϕ, plays a crucial role in the analysis, as it governs the degree of asymmetry in the response of inflation to positive versus negative shocks. We set $\phi = 0.005$ to match the asymmetry in the empirical impulse responses 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 U.S.[15] Given the value of ϕ, we set the share parameter in the CES production function to $\alpha = 0.9$, yielding a steady-state cost share of the non-labor input of 2 percent in our model. This number roughly corresponds to the long-term global expenditure on crude oil as a fraction of world GDP (Baqaee and Farhi, 2019).

[15] Gagliardone and Gertler (2024) 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.

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 $\sigma_i = 0.005$ to obtain a 1 percentage point increase in the (annualized) nominal interest rate to a one-standard-deviation contractionary monetary shock, as in the empirical impulse response shown in Panel A in Figure 2.3. Similarly, the value $\sigma_X = 0.0048$ implies that a one-standard-deviation negative supply shock raises (annualized) inflation by 1.0 percentage point in our model, as in the empirical impulse response shown in Panel B in Figure 2.3.

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_i and L_i, as $\phi \to 0$. Proposition 1 summarizes this mechanism.

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

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

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

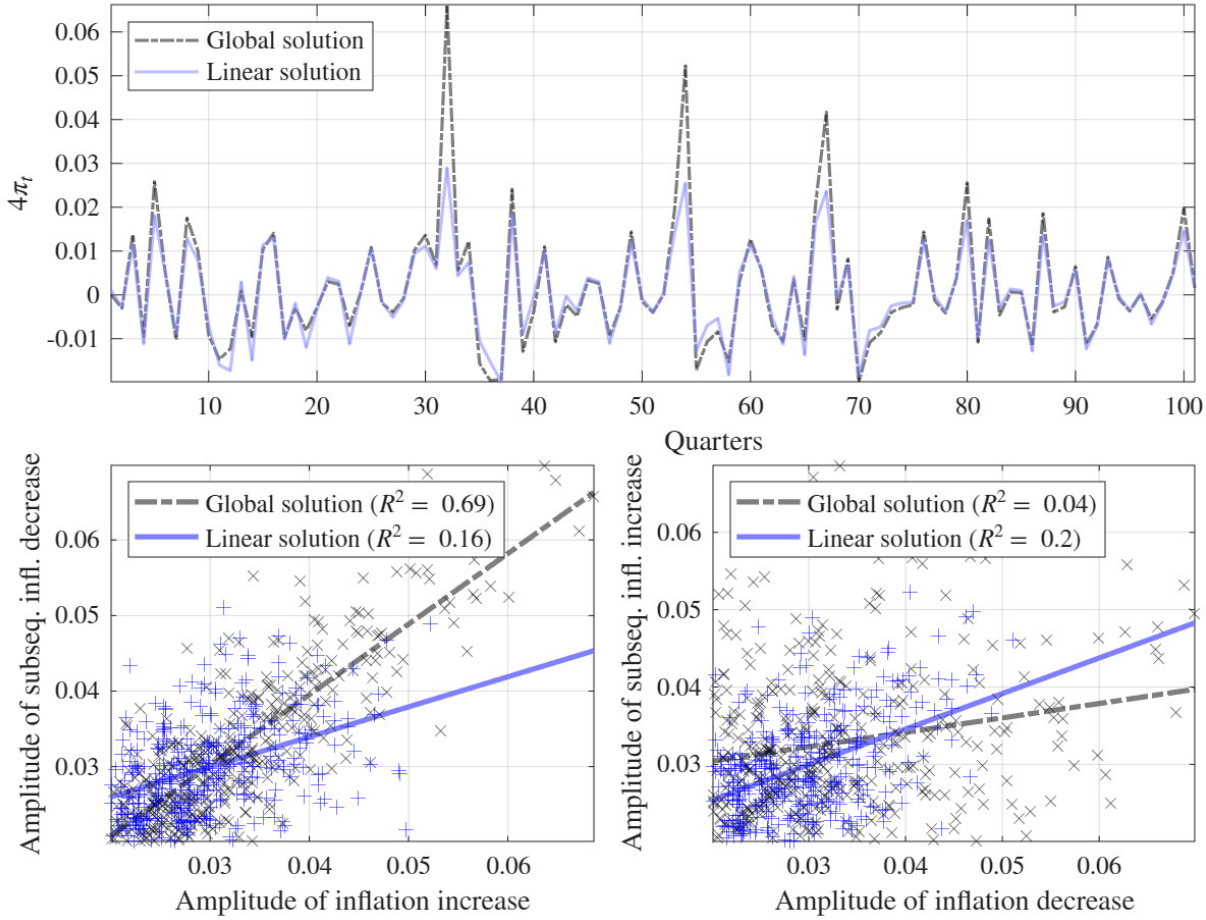


Figure 4.1. Inflation plucking cycles. This figure compares a linearized solution to that of a global. The upper panel shows two inflation time series of 100 quarters each. The lower panels display the model-implied plucking property of inflation from two simulations of 2900 quarters each, along with the simple OLS relationships.

marginal costs explode. This asymmetry drives the inflation plucking cycles in the model.[16]

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. Each simulation spans 2900 quarters, which ensures that we obtain approximately the same number of observations from the model as we have in the OECD data shown in Table 2.1. 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

[16] In Appendix B.4, we verify that the model cannot generate inflation plucking cycles unless the substitution elasticity, ϕ, is close to zero.

	Global solution		Linear solution	
Regressor:	Increase	Decrease	Increase	Decrease
Regressand:	Subseq. decrease	Subseq. increase	Subseq. decrease	Subseq. increase
$\hat{\beta}_1$	0.93^{***} (0.03)	0.19^{***} (0.04)	0.40^{***} (0.05)	0.46^{***} (0.05)
R^2	0.69	0.04	0.16	0.20
n	395	395	344	344

Table 4.1. Plucking property of model inflation. This table reports OLS regression results. The asterisk *** denotes significance at the 1 percent level.

its deterministic steady state value. In contrast, inflation in the nonlinear model is skewed to the right. In most periods, inflation dynamics are very similar in the two models, but, occasionally, a large negative supply shock and/or a large expansionary monetary policy shock generate 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 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 roughly a one-for-one empirical relationship between increases in inflation and subsequent reductions. This relationship is statistically significant at the 1 percent level, and the R^2 of the regression is 0.69. The statistical relationship between decreases in inflation and subsequent increases is very weak. The regression coefficient, $\hat{\beta}_1 = 0.19$, is low, albeit statistically significant, 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 the regression results from the data shown in Table 2.1.

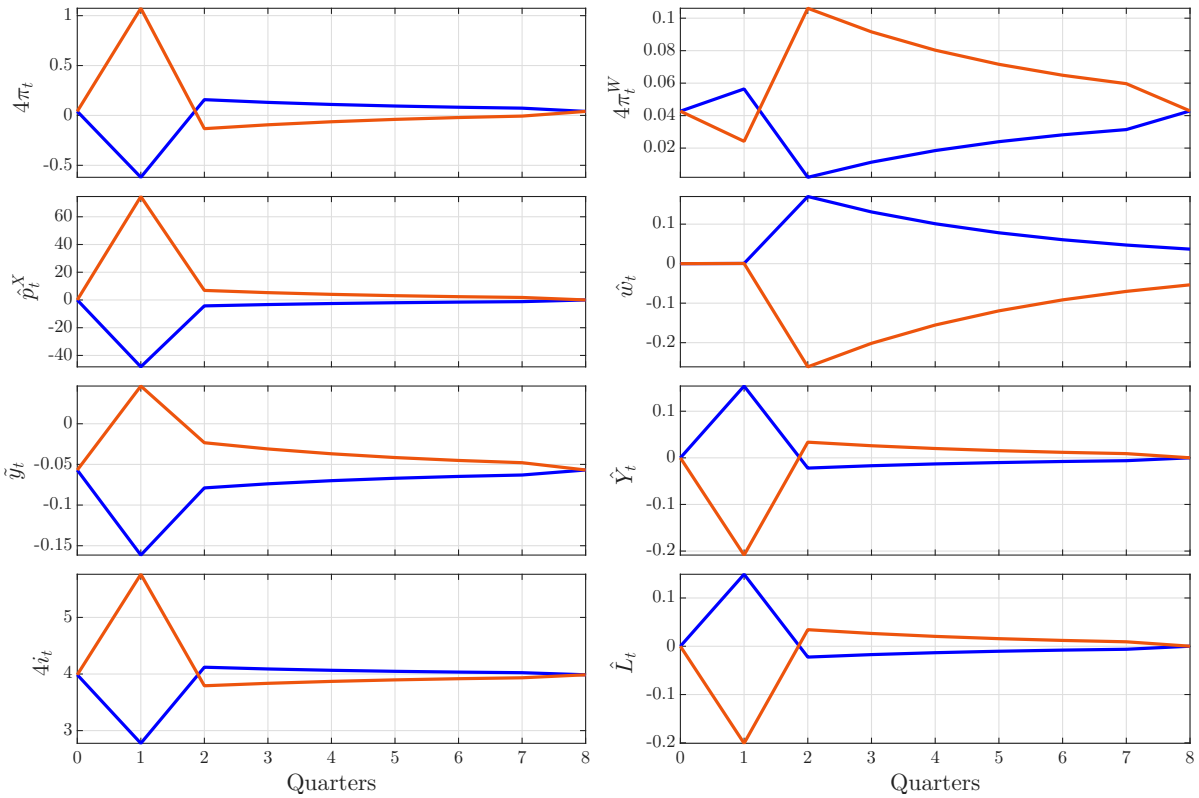


Figure 4.2. Impulse response functions. Impulse responses to one-standard-deviation negative (red) versus positive (blue) supply shocks in the baseline economy with a Taylor rule. Hatted variables are denoted in percentage deviations from the stochastic steady state.

4.3 Impulse responses

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 Positive versus negative supply shocks

Figure 4.2 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. Particularly, a negative supply shock generates a stronger response of *both* inflation and output than a positive supply shock. Inflation increases by around 1 percentage point in response to a negative supply shock and declines by around 70 basis points in response to a positive supply shock, well in line with the data in Figure 2.3. Similarly, the output responses from the model match the data in Figure 2.3 reasonably well.

The asymmetric responses from the model stem from the kinked marginal cost function (4.1). Intuitively, a negative shock to the supply of the non-labor production

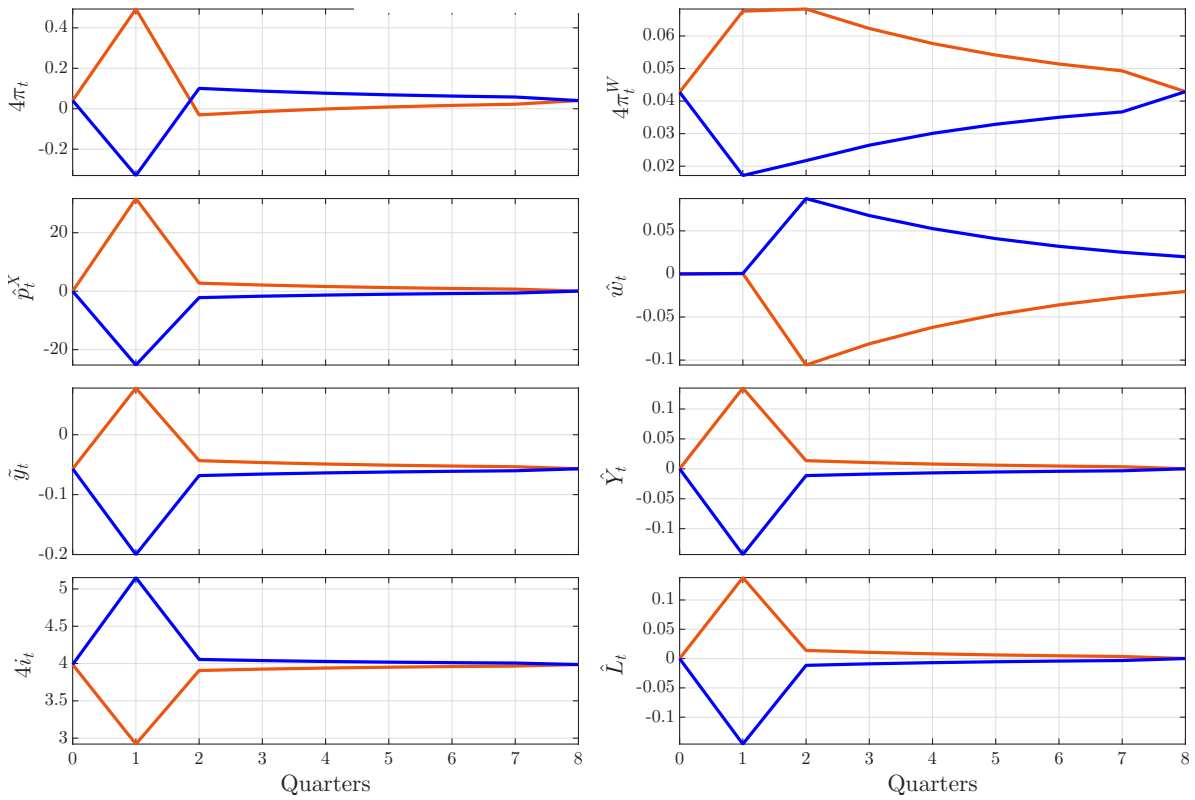


Figure 4.3. Impulse response functions. Impulse responses to one-standard-deviation expansionary (red) versus contractionary (blue) monetary policy shocks in the baseline economy with a Taylor rule. Hatted variables are denoted in percentage deviations from the stochastic steady state.

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. The rise in inflation is accompanied by a large increase in the non-labor input price p_t^X. Conversely, a positive supply shock raises output and lowers inflation, but the effect is noticeably weaker.

Figure 4.2 shows that the strong inflation response to a negative supply shock induces a sharp reduction in the real wage. Since wages are relatively rigid, this is followed by a long-lasting period of high positive wage inflation. The figure also shows that the Taylor rule entails an asymmetric response of the nominal interest rate to supply shocks. Intuitively, the Taylor rule (3.13) with the coefficients from Table 3.1 responds more strongly to movements in inflation than to movements in the output gap. Since a negative supply shock disproportionally raises inflation, the policy rate responds more strongly to the negative shock.

4.3.2 Expansionary versus contractionary monetary policy shocks

Figure 4.3 shows the impulse responses from the nonlinear model to one-standard-deviation expansionary versus contractionary monetary policy shocks. Again, the

nonlinear model generates asymmetric impulse responses that are broadly consistent with the empirical impulse responses in Figure 2.3. Particularly, an expansionary monetary 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. Inflation increases by around 40 basis points in response to an expansionary shock, while it declines by around 30 basis points to a contractionary shock, closely mimicking the data in Figure 2.3. Similarly, the model can match the output response to an expansionary monetary shock reasonably well, while it underestimates the response to a contractionary shock.

In the nonlinear model, an expansionary monetary policy shock puts upward pressure on output and inflation. But since the non-labor production input is in fixed supply and cannot easily be substituted with labor, the output response becomes relatively muted, while the inflation response becomes relatively strong. Conversely, a contractionary monetary shock generates a large reduction in output, whereas the inflation response is relatively weak. Similarly to a negative supply shock, an expansionary monetary shock leads to a relatively large decline in the real wage, which is followed by a long-lasting period of positive wage inflation.

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 here 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 (loglinearized) 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

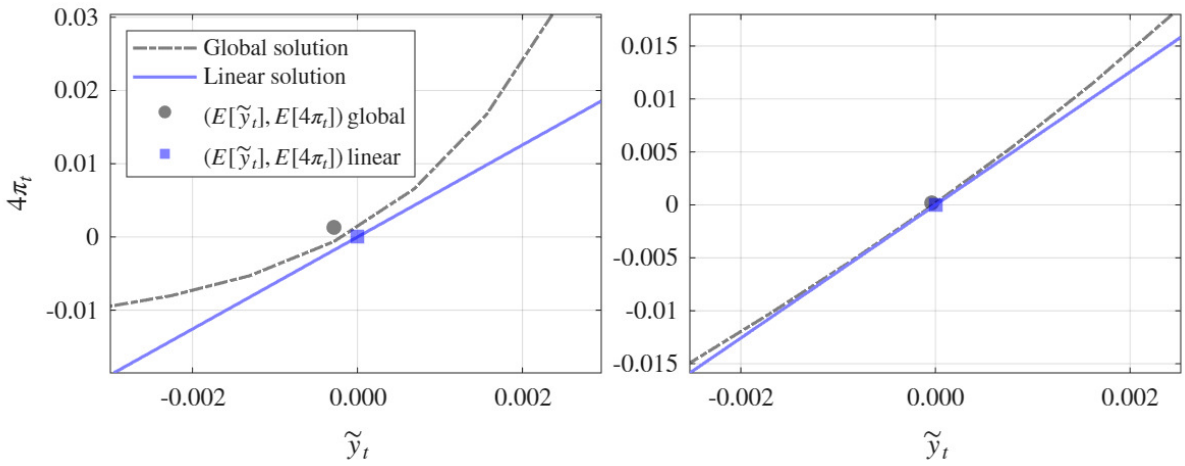


Figure 4.4. Phillips curves. The figure shows the Phillips curve relationship implied by the linear and nonlinear models with flexible wages, conditional on supply shocks (left panel) and monetary policy shocks (right panel), respectively.

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 central bank's inflation target on average) and a negative output gap bias (average output falls short of its efficient level). Conditional on supply shocks, we obtain $\mathbb{E}[4\pi_t] = 0.12\%$ and $\mathbb{E}[\tilde{y}_t] = -0.03\%$. 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' nonlabor 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 solution. However, in Appendix B.2, 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? 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. 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 that, in response 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. 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. 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

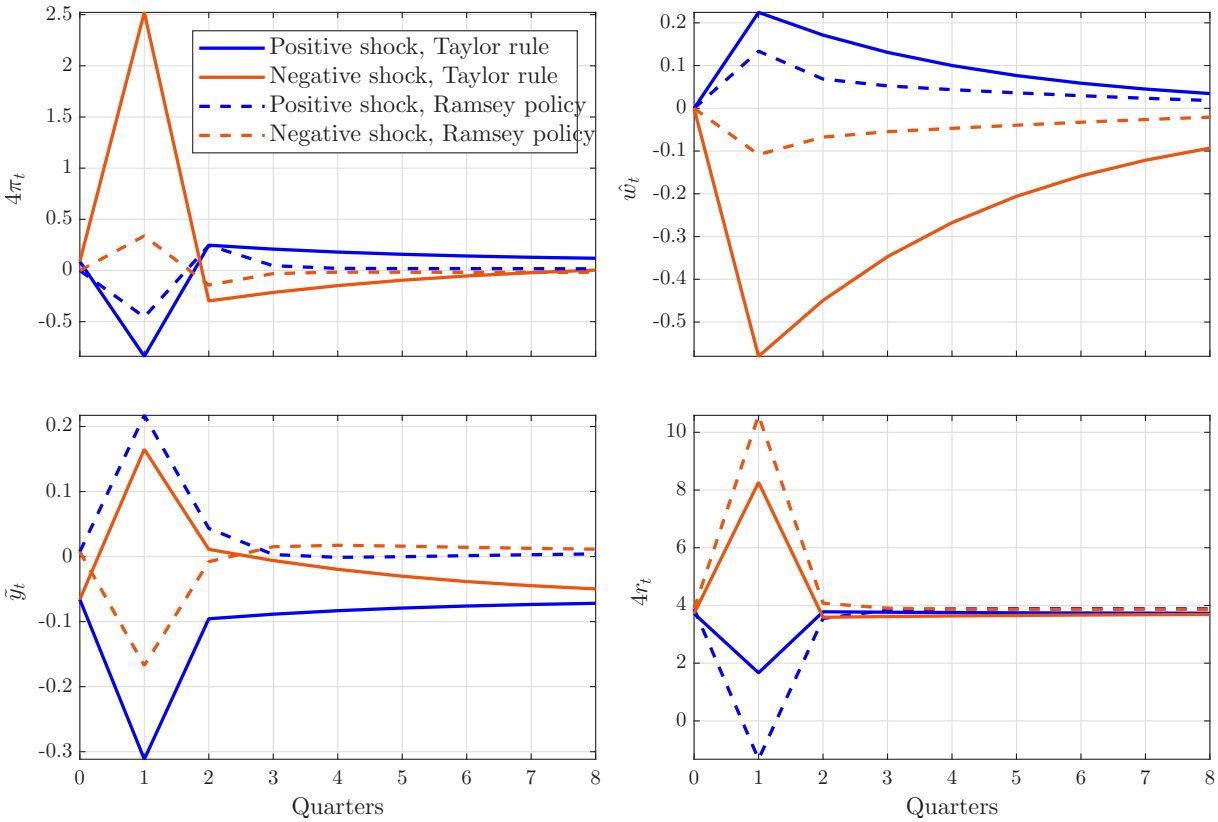


Figure 5.1. Impulse responses, Taylor rule versus Ramsey policy. Impulse responses to large (2 std. dev.) negative (red) versus positive (blue) supply shocks with a Taylor rule (solid lines) versus the Ramsey policy (dashed lines), respectively. The model is solved using a fifth-order perturbation approximation. Hatted variables are denoted in percentage deviations from the stochastic steady state.

real interest rate (which raise output) have virtually no impact on inflation. Again, this can be attributed to the convex Phillips 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 stochastic 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 in the stochastic steady state. Figure 5.1 shows that the Ramsey planner corrects these biases: Both inflation and the output gap are indistinguishable from zero in the stochastic steady state. Thus, a relatively strong, asymmetric response to supply shocks serves to reduce the average rate of inflation and raise the average level of output in the stochastic steady state. In the following section, we show that such level effects 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 out-

put 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).[17] In contrast, in the nonlinear model from Section 3, inflation exceeds the central bank's inflation target on average, while average output falls short of its average potential level. What are the welfare implications of these level effects? In this section, we show that the welfare costs of business cycles are considerably larger in the nonlinear model relative to its linearized counterpart. We also show that the additional welfare losses in the nonlinear model can almost exclusively be attributed to level effects. Fortunately, the Ramsey planner can nearly eliminate these level effects and the associated welfare losses.

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 relative to the flexible price 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 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 standard deviation of the supply shock, σ_X. In contrast, the welfare loss increases rapidly in the nonlinear version of the model. What explains this difference? The two 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 $SD(\tilde{y}_t)$, behave very similarly in the two models, the unconditional means, $\mathbb{E}(\pi_t)$ and $\mathbb{E}(\tilde{y}_t)$, do not.

Specifically, $\mathbb{E}(\pi_t)$ and $\mathbb{E}(\tilde{y}_t)$ remain constant in the linear model, as we increase the value 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 shown in the upper panel Figure 5.2 are almost exclusively driven by level effects, which, by construction, are absent in linear models.[18]

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

[18] We have verified that the welfare losses in the linear and nonlinear models with a Taylor rule are

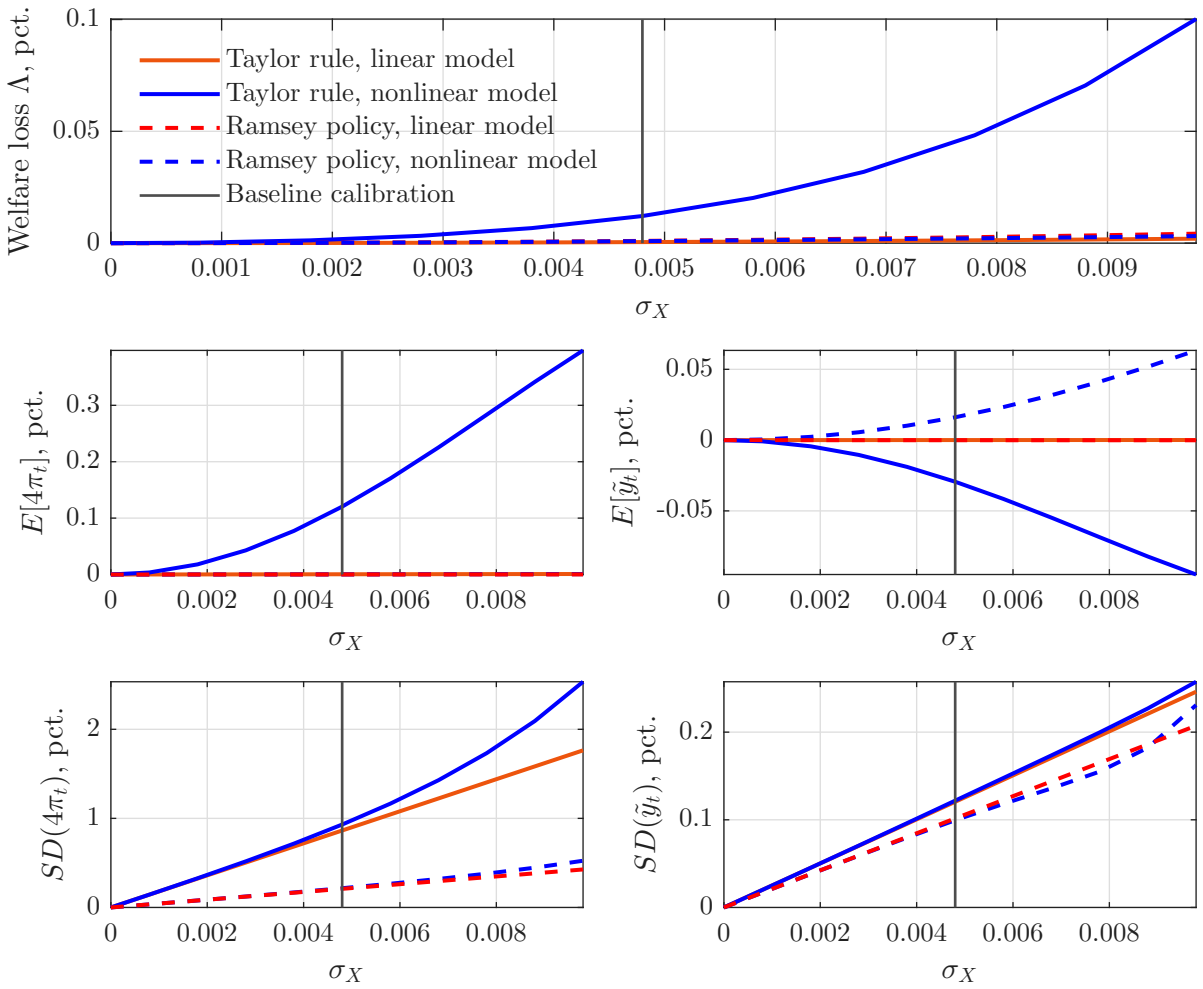


Figure 5.2. Welfare loss. Consumption-equivalent welfare loss relative to welfare when prices are completely flexible. The nonlinear model is solved using a fifth-order perturbation approximation.

Figure 5.2 also shows that the welfare losses in the nonlinear model are much lower 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.[19] Intuitively, the Ramsey planner's asymmetric response to positive versus negative supply shocks serves to reduce the average level 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.[20]

virtually identical when we abstract from level effects.

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

[20]The average output gap becomes slightly positive because the Ramsey policy entails a higher real interest rate than a Taylor rule.

6. Conclusion

We provide strong empirical evidence that inflation rates in nearly all OECD countries display "plucking cycles": Increases in inflation are followed by decreases of similar amplitude. But the amplitude of a decrease does not predict the amplitude of the subsequent increase. We then provide econometric evidence that both monetary policy shocks and supply shocks have asymmetric effects of inflation that are consistent with this plucking property: Negative supply shocks and expansionary monetary policy shocks have relatively large effects on inflation, while positive supply shocks and contractionary monetary shocks have relatively weak effects.

Next, 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 large welfare gains.

Appendices

A. Empirical results

A.1 Data

The data consists of 4-quarter inflation rates from the OECD.[21] Inflation data for most countries covers 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.

[21] 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 (1.27)	0.70^{***} (0.21)	0.50	11	5.54^{**} (2.23)	-0.08 (0.46)	0.00	10
New Zealand	1960Q1-2023Q3	2.35 (2.04)	0.62^{*} (0.29)	0.26	13	4.24^{**} (1.61)	0.33 (0.21)	0.17	12
Norway	1960Q1-2024Q2	1.53 (1.12)	0.69^{***} (0.19)	0.50	13	4.67^{**} (1.61)	0.11 (0.28)	0.01	13
Poland	1996Q1-2024Q2	2.92 (1.65)	0.87^{***} (0.13)	0.79	12	4.42 (6.44)	0.58 (0.76)	0.05	11
Portugal	1960Q1-2024Q2	2.81 (2.88)	0.70^{**} (0.26)	0.33	15	11.84^{***} (2.34)	-0.20 (0.20)	0.07	15
Slovakia	1992Q1-2024Q2	1.06 (0.72)	1.01^{***} (0.07)	0.97	6	5.03 (3.28)	0.24 (0.30)	0.09	6
Slovenia	1981Q1-2024Q2	-7.76 (5.58)	1.04^{***} (0.01)	1.00	15	224.01 (194.97)	0.00 (0.25)	0.00	15
South Korea	1960Q1-2023Q3	6.33^{**} (2.46)	0.32 (0.21)	0.11	19	6.02^{**} (2.68)	0.32 (0.23)	0.09	19
Spain	1960Q1-2024Q2	0.09 (3.83)	1.00^{*} (0.44)	0.36	9	9.85^{***} (1.84)	-0.26 (0.18)	0.19	9
Sweden	1960Q1-2024Q2	0.44 (1.64)	0.94^{**} (0.30)	0.43	13	5.26^{***} (1.48)	0.08 (0.25)	0.01	13
Switzerland	1960Q1-2024Q2	0.66 (0.76)	0.89^{***} (0.15)	0.79	9	3.34^{*} (1.66)	0.23 (0.33)	0.05	9
Turkey	1960Q1-2024Q2	4.42 (3.51)	0.69^{***} (0.13)	0.52	28	18.27^{***} (5.26)	0.06 (0.21)	0.00	27
United Kingdom	1960Q1-2024Q2	2.48 (1.65)	0.65^{***} (0.18)	0.56	10	9.88^{**} (3.00)	-0.33 (0.35)	0.08	10
United States	1960Q1-2024Q2	-0.21 (1.55)	1.05^{***} (0.27)	0.62	9	5.02^{**} (1.64)	0.07 (0.27)	0.01	9

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

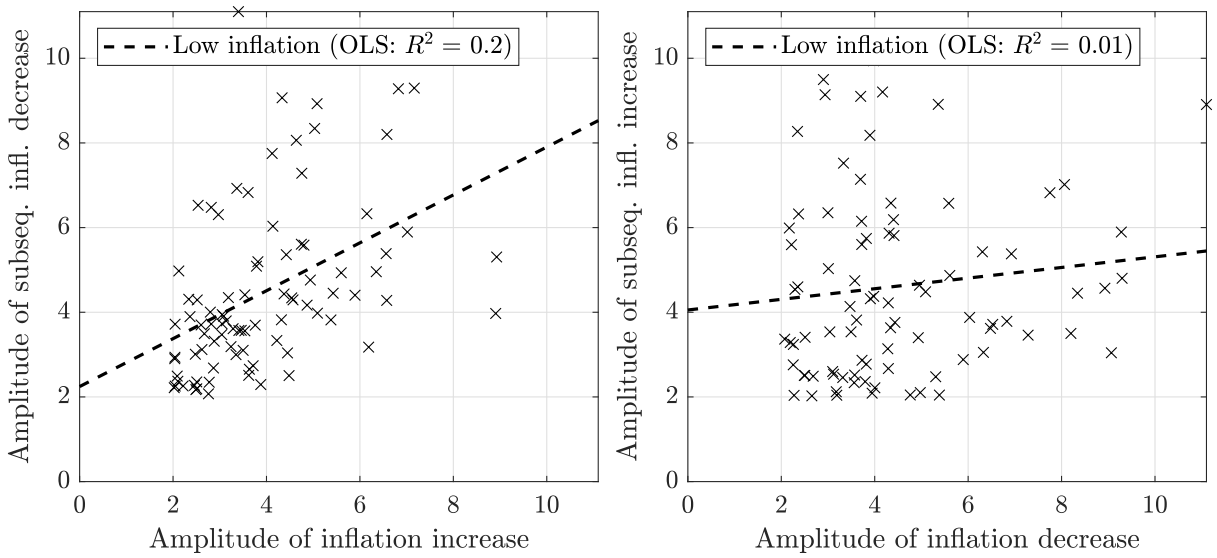


Figure A.1. Inflation plucking cycles in low-inflation regimes. This figure displays scatter plots of amplitudes of inflation cycles for low inflation regimes from pooled cross-country OECD observations. The dashed lines are univariate OLS regression lines.

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

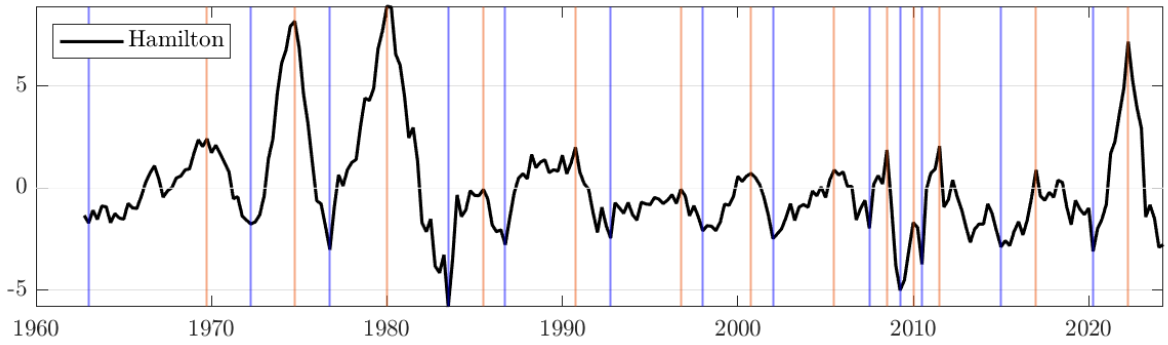


Figure A.2. De-trended US inflation. This figure displays quarterly data on US Hamilton-filtered detrended CPI inflation along with marked inflation peaks (red) and troughs (blue).

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.

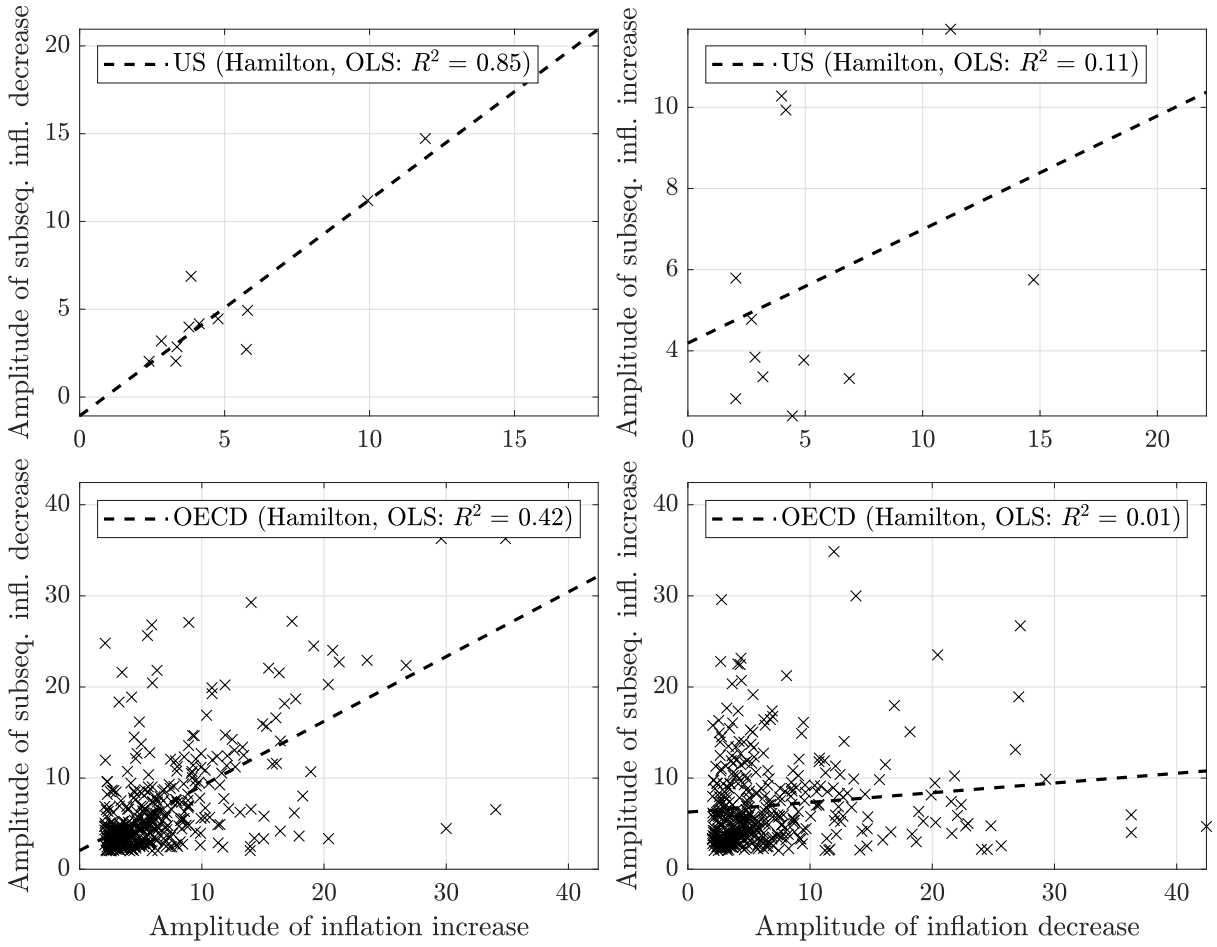


Figure A.3. Inflation plucking cycles (Hamilton filter). This figure displays scatter plots of amplitudes of de-trended inflation cycles for the US (upper panels) and the OECD countries (lower panels).

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 and the (proxy) interest rate. We allow for an intercept in each equation, a quintic time trend for (log) GDP and quadratic time trends for inflation and the interest rate. 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. 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

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

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

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

with

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

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

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

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). Reorganzing the first-order conditions yields (3.8) and (3.9).

The pricing problem of the firm (3.10) has the Lagrangian:

$$\mathcal{L} = \mathbb{E}_t \sum_{j=0}^{\infty} q_{t,t+j} \left\{ \frac{P_{it}}{P_t} Y_{it} - mc_{it} Y_{it} - Y_{it} \right\},$$

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}$$

$$\frac{\partial \mathcal{L}}{\partial mc_t} = \mu_{3t}\left[\frac{\varepsilon}{\gamma_P}\right] + \mu_{4t}\left[\left[\frac{w_t}{\alpha}\right]^{-\phi}\phi mc_t^{\phi-1}Y_t\right] + \mu_{5t}\left[\left[\frac{p_t^X}{(1-\alpha)}\right]^{-\phi}\phi mc_t^{\phi-1}Y_t\right] = 0,$$

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

The above derivatives are defined below

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

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:

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

■

B.2 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 seven realizations and wages into a grid of 701 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 701×49 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

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

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.3 Accuracy of perturbation

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

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

where U^{pa} is a perturbation approximation of the per-period utility, and U is its exact value from the global solution. Intuitively, Ξ has the interpretation of percentage

deviations from the true utility.

Table B.1 summarizes the error measures for rising orders of perturbation approximations. As the order rises, the mean approximation error strictly declines.

Perturbation	First order	Second order	Third order	Fourth order	Fifth order
$\mathbb{E}(\Xi)$	0.0122	0.0052	0.0044	0.0043	0.0040

Table B.1. Accuracy of perturbation. This table reports various accuracy measures for perturbation of increasing order using the per-period 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.

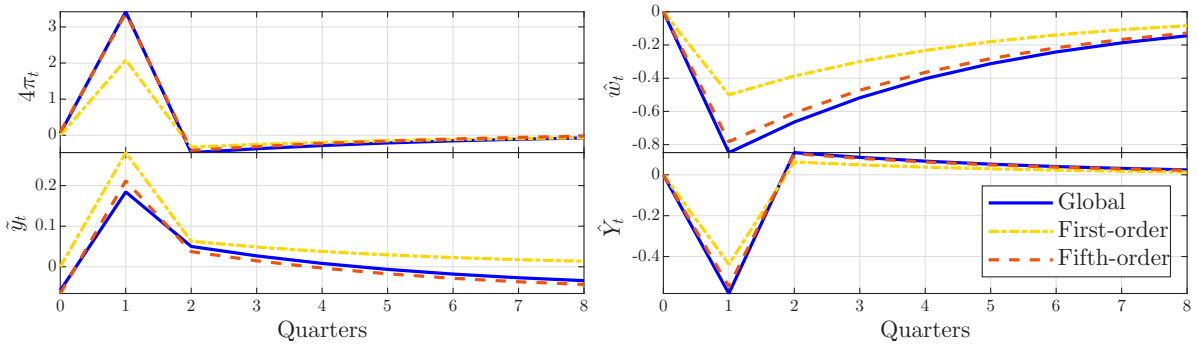


Figure B.1. Impulse response functions. Impulse responses to a large negative supply shock using a global (blue), Dynare's first-order (yellow), and fifth-order (red) solution, respectively. Hatted variables are denoted in percentage deviations from the stochastic steady state.

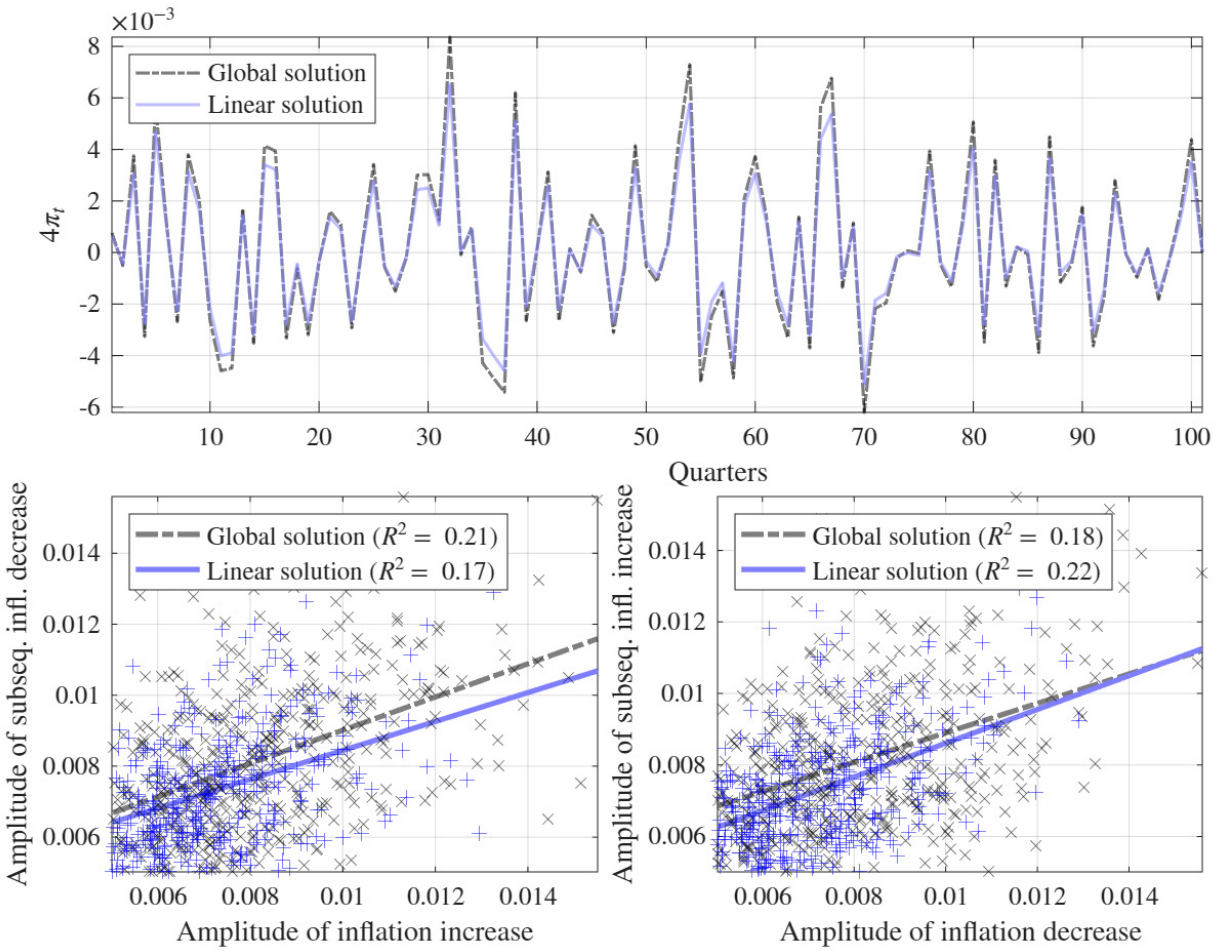


Figure B.2. Robustness of inflation plucking cycles. This figure compares a linearized solution to that of a global for $\phi = 0.1$. The remaining parameters are set to their baseline values shown in Table 3.1. The hyperparameter used to identify peaks and troughs is set to 0.5 percent. The upper panel shows two inflation time series of 100 quarters each. The lower panels display the model-implied plucking property of inflation from two simulations of 2900 quarters each, along with the simple OLS relationships.

B.4 Robustness: Elasticity of substitution

Figure B.2 shows the relationship between amplitudes of inflation increases and decreases in model-generated data, analogous to Figure 4.1 in the main paper but for a higher value of the elasticity of substitution, ϕ. For this exercise, we set the value of the hyperparameter used to identify peaks and troughs to 0.5 percent, which ensures that we obtain roughly the same number of observations from the linear model as in the OECD data shown in Figure 2.2. As Figure B.2 shows, the global solution is virtually identical to the linearized solution when $\phi = 0.1$. Thus, the nonlinear model's ability to reproduce the inflation plucking cycles observed in the data relies crucially on the (empirically plausible) assumption that ϕ is close to zero.

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