Inflation Plucking Cycles*

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February 28, 2025

Preliminary, comments welcome

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 show that the fully nonlinear version of a standard New Keynesian model, extended with a scarce non-labor input with low substitutability in production, can match this finding. The model gives rise to a highly convex price Phillips curve, a positive inflation bias, and a negative output gap bias. Optimal monetary policy responds aggressively to large negative supply shocks while accommodating large positive ones. This policy serves to dampen the inflation plucking cycles, reduce the inflation bias, and raise the average output level, yielding sizable welfare gains.

Keywords: Inflation, Phillips curve, Optimal monetary policy, Plucking cycles
JEL classification: E31, E32, E37, E52, E58

*We would like to thank Søren Hove Ravn and Pontus Rendahl for their valuable comments.

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1. Introduction

We document a new fact about inflation dynamics in advanced economies. Specifically, we show that inflation displays ”plucking” cycles: A tendency for inflation to rise temporarily above its longer-term trend but rarely drop below it. The plucking property has the following testable implication: Increases in inflation are followed by decreases of similar amplitude, while 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.

To explain the inflation plucking cycles, 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 key source of nonlinearity in the model is the non-labor production input, which we broadly interpret as, e.g., energy or specialized capital. 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. This asymmetric response of marginal costs gives rise to inflation plucking cycles similar to those observed in the data.

The presence of inflation plucking cycles has first-order implications for welfare and monetary policy. In standard linearized models, inflation fluctuates symmetrically around the central bank’s inflation target and output around its potential level. In these models, stabilization policy has no effect on average levels, hence the welfare gains of such policy are 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 lead to disproportionally large increases in inflation, whereas positive supply shocks lead to disproportionally large reductions in the output gap. Due to this asymmetry, the welfare costs of business cycles are significantly higher in the nonlinear model relative to its linearized counterpart.

How should monetary policy respond to inflation plucking cycles? To answer this question, we solve the fully nonlinear Ramsey problem under commitment. We obtain the following results.

First, when wages are fully flexible, the divine coincidence holds. Hence the central bank fully stabilizes inflation and the output gap, as in standard linear models. The welfare gains of stabilization policy are, however, considerably larger in the nonlinear version than in the linearized version of the model. Intuitively, if the central bank follows the Ramsey policy instead of a standard Taylor rule, this serves to lower 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.

Next, when wages are sticky, monetary policy faces the standard trade-off between stabilizing price inflation, wage inflation, and the output gap, respectively. Subject to small shocks, the nonlinear model behaves like its linearized counterpart. For instance, in response to a small negative supply shock, the Ramsey planner allows for a positive output gap, moderate price inflation, and wage deflation, thus facilitating a reduction in the real wage (and vice versa for a small positive supply shock).

Large negative supply shocks, on the other hand, call for a more hawkish response. Under a standard Taylor rule, inflation will disproportionally increase, leading the real wage to drop substantially below its natural level. This is followed by a long-lasting period of costly nominal wage adjustment. As a result, the welfare costs of negative supply shocks are disproportionally higher for large shocks than for small shocks. Accordingly, optimal monetary policy responds much more aggressively to large negative supply shocks. By utilizing the convexity of the price Phillips curve, the central bank can facilitate a sizable disinflation without significantly lowering the output gap.

Lastly, large positive supply shocks call for an accommodative monetary policy. Due to the convexity of the price Phillips curve, large positive shocks do not generate significant disinflationary pressures. As a result, the Ramsey planner accommodates these shocks.

The asymmetric response to supply shocks enables the Ramsey planner to almost fully correct the inflation and output gap biases that arise when the central bank follows a standard symmetric Taylor rule. Specifically, by responding aggressively to large negative supply shocks while accommodating large positive ones, the Ramsey planner dampens the inflation plucking cycles, which in turn lowers the average rate of inflation and raises the average level of output.

Related literature. Friedman (1964, 1993) introduced the concept of "plucking cycles" 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. Friedman (1964) noted that a testable implication of the plucking theory 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 (2024) provide strong empirical evidence that the behavior of the US unemployment rate is consistent with this pattern.[1] They show that

[1]The literature on plucking cycles is scarce. Kim and Nelson (1999) and Sinclair (2010) use econometric models to test Friedman's plucking theory. Hartley (2021) and Kohlscheen, Moessner, and Rees

a search model with downward nominal wage rigidity can account for the plucking property of the unemployment rate. To the best of our knowledge, our paper is the first to extend the concept of "plucking" to inflation dynamics.

Our model gives rise to a convex price Phillips curve. The original contribution of Phillips (1958) and, more recently, Boehm and Pandalai-Nayar (2022) provide empirical evidence in favor of a convex Phillips curve.[2] Post-pandemic inflation has spurred a large amount of literature on nonlinearities in the Phillips curve relationship, including Cerrato and Gitti (2022), Harding, Lindé, and Trabandt (2023), Benigno and Eggertsson (2024), and Blanco et al. (2024). 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 the optimal Ramsey 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. De Polis, Melosi, and Petrella (2024) study optimal monetary policy in a linearized model with perceived skewness in the distribution of markup shocks.

Roadmap. The rest of the paper is organized as follows. Section 2 contains empirical evidence on inflation plucking cycles in advanced economies. In Section 3, we propose a New Keynesian model with a scarce non-labor production input. In Section 4, we show that the nonlinear version of the model can generate inflation plucking cycles similar to those observed in the data. In Section 5, we investigate the implications for monetary policy. Section 6 concludes.

2. Empirical evidence

This section shows that inflation rates in the US and most other OECD countries display plucking cycles. We start by collecting quarterly inflation data on all 38 OECD countries. For most countries, these data are available for 1960Q1 to 2024Q2 (for details, see Appendix A). As a baseline, we exclude "extreme" observations from our dataset, which we define as inflation rates above 50 percent per year. In these cases,

(2024) present cross-country evidence of plucking cycles in output and unemployment, respectively.

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

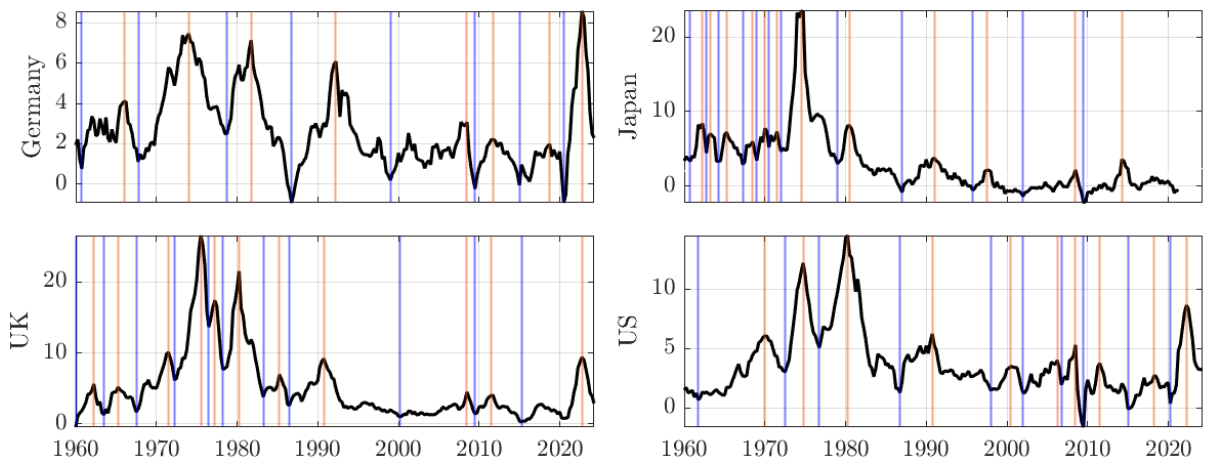

Figure 2.1. Inflation peaks and troughs This figure displays quarterly data on inflation from 1960Q1 to 2024Q2, along with marked peaks of inflation (red) and troughs (blue) for Germany, Japan, the United Kingdom, and the United States.

we start the country-specific sample on the date of the subsequent inflation trough, excluding all prior observations.[3]

Next, we identify inflation peaks and troughs in the data using the algorithm developed by Dupraz, Nakamura, and Steinsson (2024).[4] 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.

Figure 2.2 illustrates the key property of inflation plucking cycles. The upper panels display US data, while the lower panels display cross-country pooled OECD data. The upper left panel contains a scatter plot of the amplitudes of observed increases in US inflation against the amplitudes of subsequent reductions.[5] 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 that there is no statistical relationship between observed reductions in US inflation and subsequent increases.

Similarly, the lower left panel in Figure 2.2 shows the amplitude of observed inflation increases in various OECD countries versus subsequent reductions. As for the US, increases in inflation forecast subsequent reductions nearly one-for-one. The rela-

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

[4]We set the threshold parameter for identifying inflation peaks and troughs 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.

[5]The amplitude of an increase is given by the difference between the peak value and the previous trough value (and vice versa for a decrease).

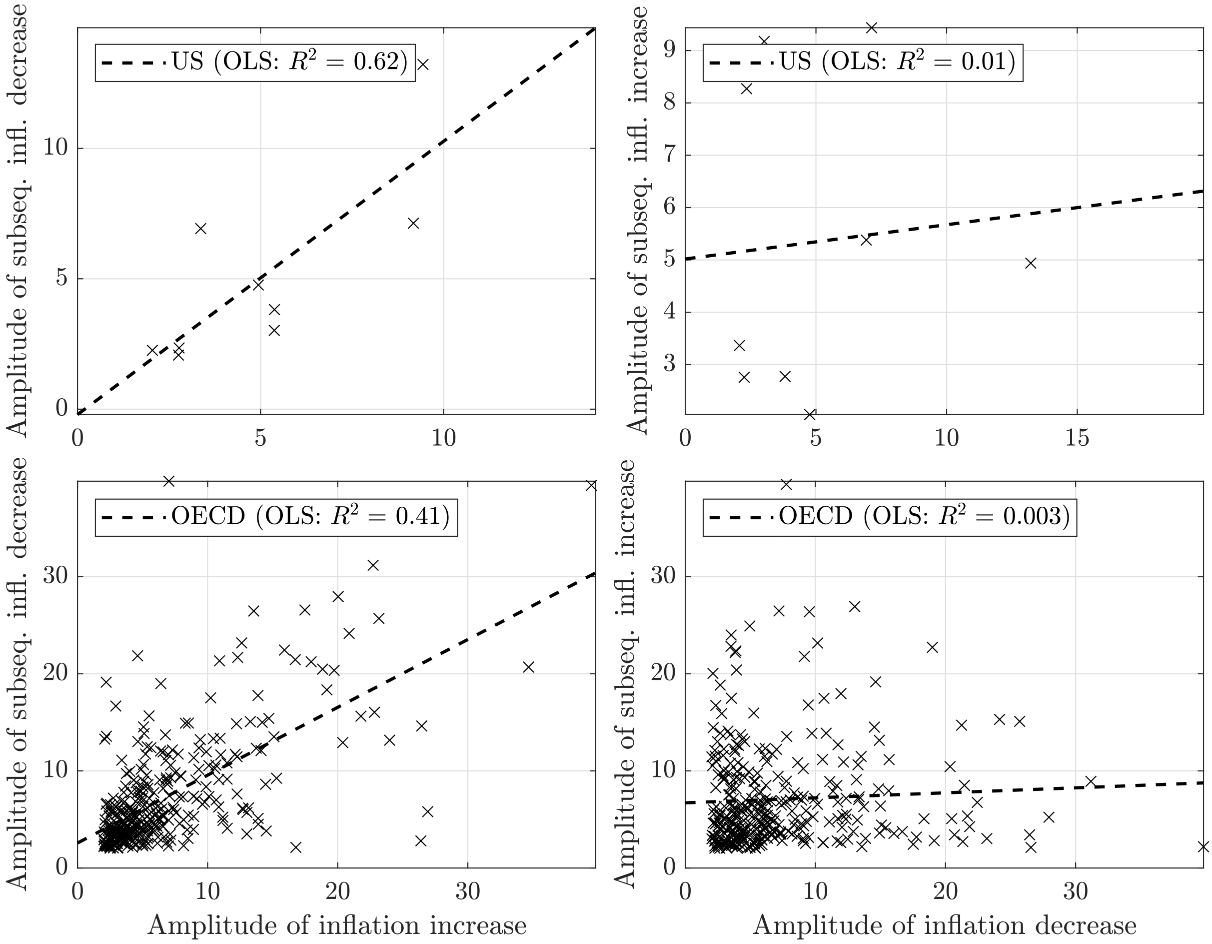

Figure 2.2. Inflation plucking cycles. This figure displays scatter plots of amplitudes of US inflation cycles (upper panels) and for cross-country pooled OECD (lower panels). The dashed lines are univariate OLS regression lines. The left panels show amplitudes of inflation increases versus subsequent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

tionship is significant at the 1 percent level with an R^2 of 0.41. Conversely, the lower right panel shows the amplitudes of observed reductions in inflation against subsequent increases in the OECD countries. Again, we observe no statistical link between increase-amplitudes and subsequent decrease-amplitudes. 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.[6] It is worth noting that countries with very different institutional arrangements and historical inflation experiences—such as Germany and Turkey—display the same plucking property. The country-specific results are shown in Tables A.2 and A.3 in Appendix A.[7]

Movements in "trend inflation" may blur the plucking property. We therefore conduct two robustness checks of our baseline empirical findings. First, in Section A.2

[6]The exceptions are Australia, Canada, France, Ireland, and South Korea.
[7]In the country-specific regressions, we use all available data.

	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)	0.70^{***} (0.05)	0.05 (0.05)
R^2	0.41	0.01	0.72	0.00
n	9	9	342	337

Table 2.1. Plucking property of inflation. This table reports OLS regression results. *, **, and *** denote significance at the 10, 5, and 1 percent levels, respectively.

in Appendix A, we show that our empirical findings are robust if we only consider "low inflation environments," which we conservatively define as countries where annual 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, in Appendix A.3, we show that our findings are robust if we de-trend our inflation data using the Hamilton (2017) filter.

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 to help explain the inflation plucking cycles observed in the data.

In the model, a continuum of monopolistically competitive households, each supplying a differentiated labor service, maximizing its 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 technology. These firms set prices subject to price adjustment costs and use labor and 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:

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

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.

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

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

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

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

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

where Π_t^W is the (gross) wage inflation rate, which is linked to the real wage as $\Pi_t^W = \Pi_t w_t / w_{t-1}$.

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

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

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

Details on the derivations are in Appendix B.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).[8]

3.2 Production

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

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

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

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

where α is a cost share parameter, and $\phi \in (0, \infty)$ is the elasticity of substitution between labor and the non-labor input.[9]

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

[9] Notable cases include $\phi \to 0$ (Leontief with perfect complementarity), $\phi \to 1$ (Cobb-Douglas), and $\phi \to \infty$ (linear with perfect substitutability).

Cost minimization yields the factor demands,

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

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

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:

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

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

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

A detailed derivation of equation (3.12) is in Appendix B.3.

3.3 Monetary and fiscal policy

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

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

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

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 in the literature
φ	Inverse Frisch elasticity	1	Standard in the literature
γ_W	Rotemberg wage adjustment costs	465.3	Wage duration of 4 quarters
ε_w	Elasticity of substitution, labor	6	Standard in the literature
	Firms		
α	CES share parameter	0.9	US plucking property (Table 2.1)
ϕ	Elasticity of substitution of inputs	0.01	US plucking property (Table 2.1)
γ_P	Rotemberg price adjustment costs	29.4	Price duration of 3 quarters
ε	Elasticity of substitution, goods	6	Standard in the literature
	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	0.011	US inflation volatility
σ_i	Standard deviation, monetary policy shock	0.013	US FFR volatility

Table 3.1. Calibration

3.4 Market clearing

The goods market clearing condition is given by:

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

3.5 Solution method

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

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.

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, ε_w, is set to 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 value of the Rotemberg wage adjustment cost parameter, $\gamma_W = 465.3$, is consistent with wages being reset every four quarters in the linearized version of the model, as in Galí (2015).

Turning to firms, we set the labor share parameter in the CES production function to $\alpha = 0.9$, and the elasticity of substitution between labor and the non-labor input to $\phi = 0.01$. These values allow us to reproduce the plucking cycles observed in US inflation data, as summarized in Table 2.1.[10] We set 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 duration is in turn consistent with the microeconometric evidence in Nakamura and Steinsson (2008). Finally, as for labor inputs, we set the elasticity of substitution with respect to intermediate goods to $\varepsilon = 6$.

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 $\rho_X = 0$. For simplicity, we treat demand and supply shocks separately, hence we turn off the monetary policy shocks in the simulations with supply shocks (and vice versa). We calibrate the standard deviation of the supply shock, σ_X, such that the standard deviation of annualized inflation is 2 percent in the model, roughly matching US inflation data. Similarly, we calibrate the standard deviation of the monetary policy shock, σ_i, such that the standard deviation of the annualized nominal interest rate is 3 percent in the model, which roughly corresponds to the volatility of the US federal funds rate.

4. Quantitative analysis

This section demonstrates that the nonlinear model can generate inflation plucking cycles similar to those observed in the data. We also show that the model gives rise to a highly convex price Phillips curve, which, coupled with a standard Taylor rule, generates a positive inflation bias and a negative output gap bias in the model.

[10] In comparison, Lorenzoni and Werning (2023) assume $\phi = 0.1$, whereas Baqaee and Farhi (2019) assume $\phi = 0.001$. The values of α and ϕ yield a steady-state output share of the non-labor input of around 3 percent in our model.

4.1 A one-period model in partial equilibrium

To clarify the source of the inflation plucking cycles, consider an intermediate firm i optimizing one-period profits in partial equilibrium, assuming a Leontief production function ($\phi \to 0$). The firm's optimization problem is to maximize dividends by setting a price

$$m_i = \max_{P_i} \left\{ \left(P_i / P \right) Y_i - mc_i Y_i \right\},$$

subject to the demand schedule, $Y_i = \left(P_i / P \right)^{-\varepsilon} Y$. By solving this problem, we obtain the well-known optimality condition,

$$\frac{P_i}{P} = \frac{\varepsilon}{\varepsilon - 1} mc_i.$$

Optimal pricing depends linearly on marginal costs, but the marginal cost is highly nonlinear in inputs due to the Leontief production structure. As a result, optimal pricing—and therefore inflation—is highly nonlinear in the production inputs (labor and non-labor). Proposition 1 summarizes this mechanism.

Proposition 1. ***Kinked marginal costs.*** *For the firm's one-period optimization problem, as $\phi \to 0$, the following marginal cost function arises*

$$mc_i = \begin{cases} \frac{w_i}{\alpha} & \text{if } X_i \geq L_i, \\ \infty & \text{if } X_i < L_i. \end{cases}$$

Proof. *See Appendix B.5.* ■

As ϕ approaches 0, that is, as labor and the non-labor input become increasingly complementary, the marginal costs become highly nonlinear. In the Leontief limit, marginal costs either become constant when X_i is relatively abundant or explode when X_i is relatively scarce. This asymmetry drives the inflation plucking cycles in the model.

4.2 Inflation plucking cycles in the model

The upper panel in Figure 4.1 shows two inflation time series snippets of 100 quarters from two model simulations spanning 1000 quarters. One simulation is from the nonlinear model (solved with global methods), and the other simulation is from the linearized version (solved with a first-order perturbation approximation). Both models use the baseline calibration from Table 3.1 and the same series of supply shocks.

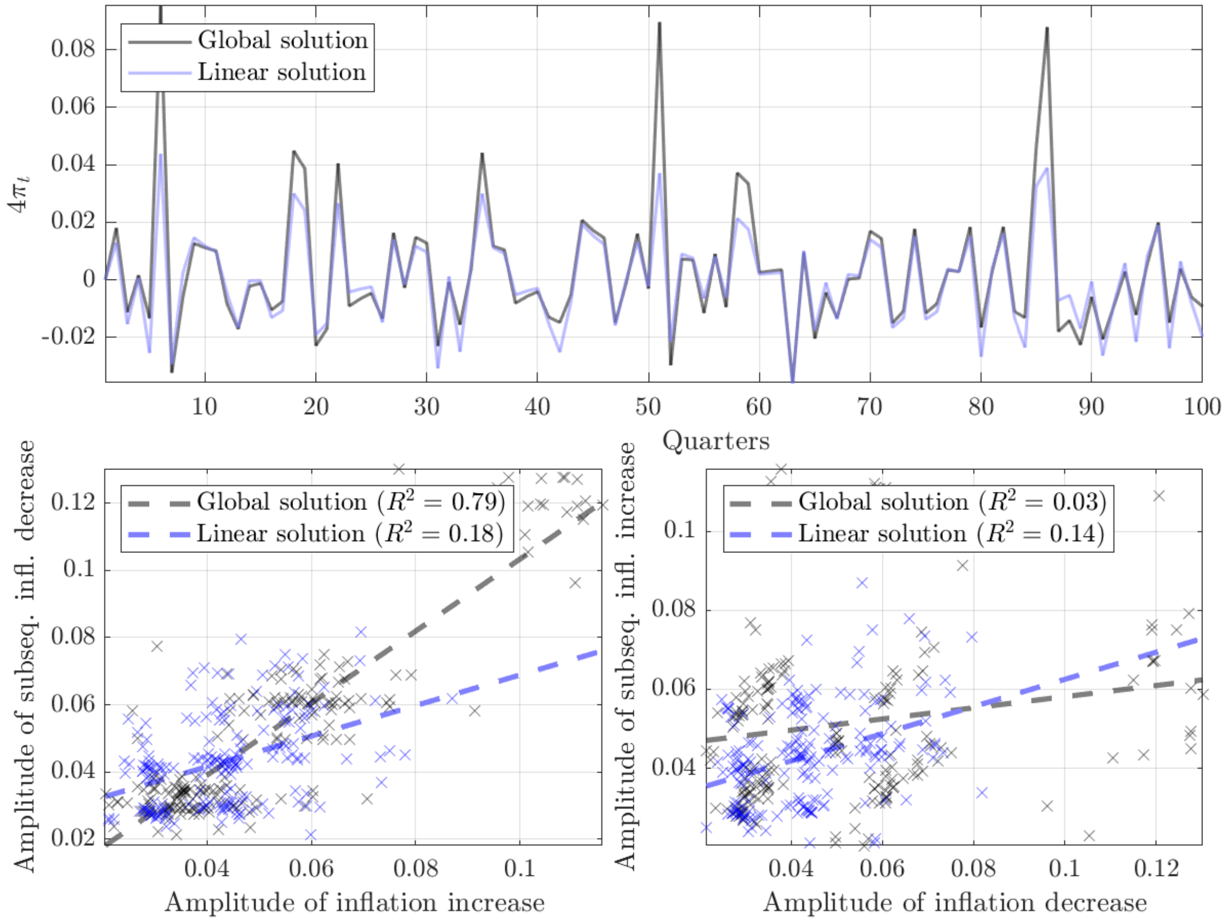

Figure 4.1. Inflation plucking cycles. This figure compares a linearized solution to that of a global. The upper panel shows two inflation time series of 100 quarters each. The lower panels display the model-implied plucking property of inflation from two simulations of 1000 quarters each, along with the simple OLS relationships.

Figure 4.1 shows that inflation in the linear model fluctuates symmetrically around its deterministic steady state value (which is assumed to be zero). In contrast, in the nonlinear model, inflation is highly skewed to the right. In most periods, inflation dynamics are very similar in the two models, but, occasionally, a large negative supply shock generates a large inflation 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 vs. subsequent decrease-amplitudes and decrease-amplitudes vs. sub-

	Global solution		Linear solution	
Regressor:	Increase	Decrease	Increase	Decrease
Regressand:	Subseq. decrease	Subseq. increase	Subseq. decrease	Subseq. increase
$\hat{\beta}_1$	1.07*** (0.04)	0.14** (0.06)	0.45*** (0.07)	0.34*** (0.06)
R^2	0.79	0.03	0.18	0.14
n	189	189	190	190

Table 4.1. Plucking property of model inflation. This table reports OLS regression results.*, **, and *** denote significance at the 10, 5, and 1 percent levels, respectively.

sequent 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 longer samples, they would be identical). Also, as the table shows, 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 R^2 of the regression is 0.79. On the other hand, the statistical relationship between decreases in inflation and subsequent increases is very weak. While the regression coefficient, $\hat{\beta}_1 = 0.14$, is significantly different from zero, it is very low, and the R^2 of the regression is near zero.[11] 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. Thus, the nonlinear model can account for the inflation plucking cycles observed in the data.

4.3 Nonlinear Phillips curve

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

$$\pi_t = \beta \mathbb{E}_t[\pi_{t+1}] + \kappa \tilde{y}_t, \tag{4.1}$$

where κ is the structural NKPC slope coefficient and $\tilde{y}_t$ is the (loglinearized) output gap. In addition, in the linearized model, it holds that $\mathbb{E}_t[\pi_{t+1}] = 0$, hence the NKPC

[11] The regression coefficient is statistically significant because the number of observations is sufficiently large to detect mean-reversion. In the cross-country OECD regressions in Table A.5, we obtain a similar result.

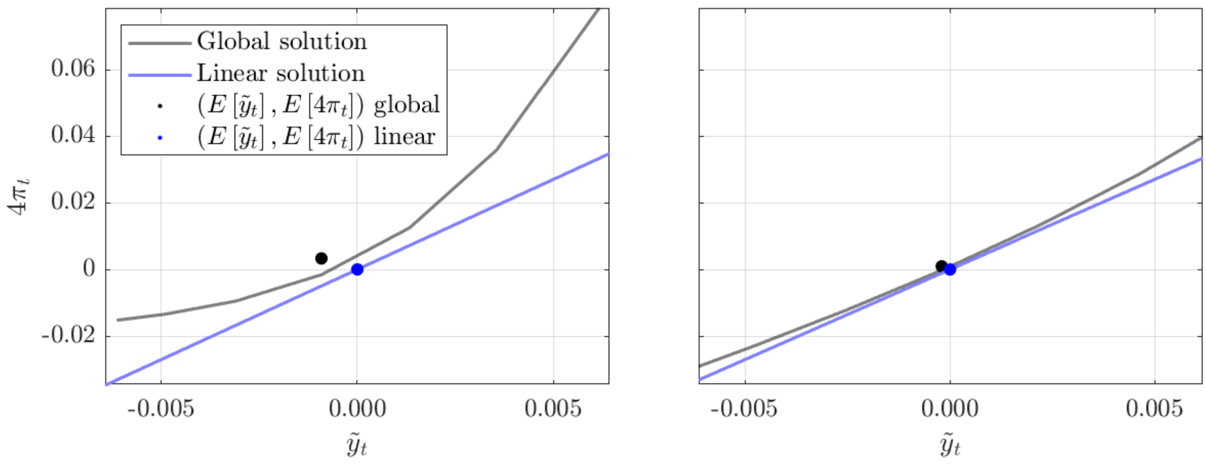

Figure 4.2. Phillips curves. The figure shows the Phillips curve relationship implied by the linear and nonlinear model, respectively, conditional on supply shocks (left panel) and monetary policy shocks (right panel).

(4.1) entails a simple linear relationship between π_t and $\tilde{y}_t$.

Figure 4.2 plots the relationship between π_t and $\tilde{y}_t$ from the linearized model conditional on supply shocks (left panel) and monetary policy shocks (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 in the linearized model, hence $\mathbb{E}[\pi_t] = 0$ and $\mathbb{E}[\tilde{y}_t] = 0$.

Figure 4.2 also shows the corresponding relationships between π_t and $\tilde{y}_t$ implied by the nonlinear model. As the figure shows, the nonlinear model yields a convex Phillips curve relationship. The convexity is conditional on both demand and supply shocks, but it is particularly strong conditional on supply shocks. Thus, large negative supply shocks lead to disproportionally large inflation bursts, whereas large positive supply shocks lead to disproportionally large reductions in the output gap. 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). These biases are direct results of a convex price Phillips curve. As Figure 4.2 shows, they arise in response to both demand and supply shocks, but they are particularly strong conditional on supply shocks. In the latter case, we obtain $\mathbb{E}[4\pi_t] = 0.3\%$ and $\mathbb{E}[\tilde{y}_t] = -0.1\%$. Later, we will show that biases of these magnitudes give rise to sizable welfare losses which, however, can be almost completely mitigated by a social planner.

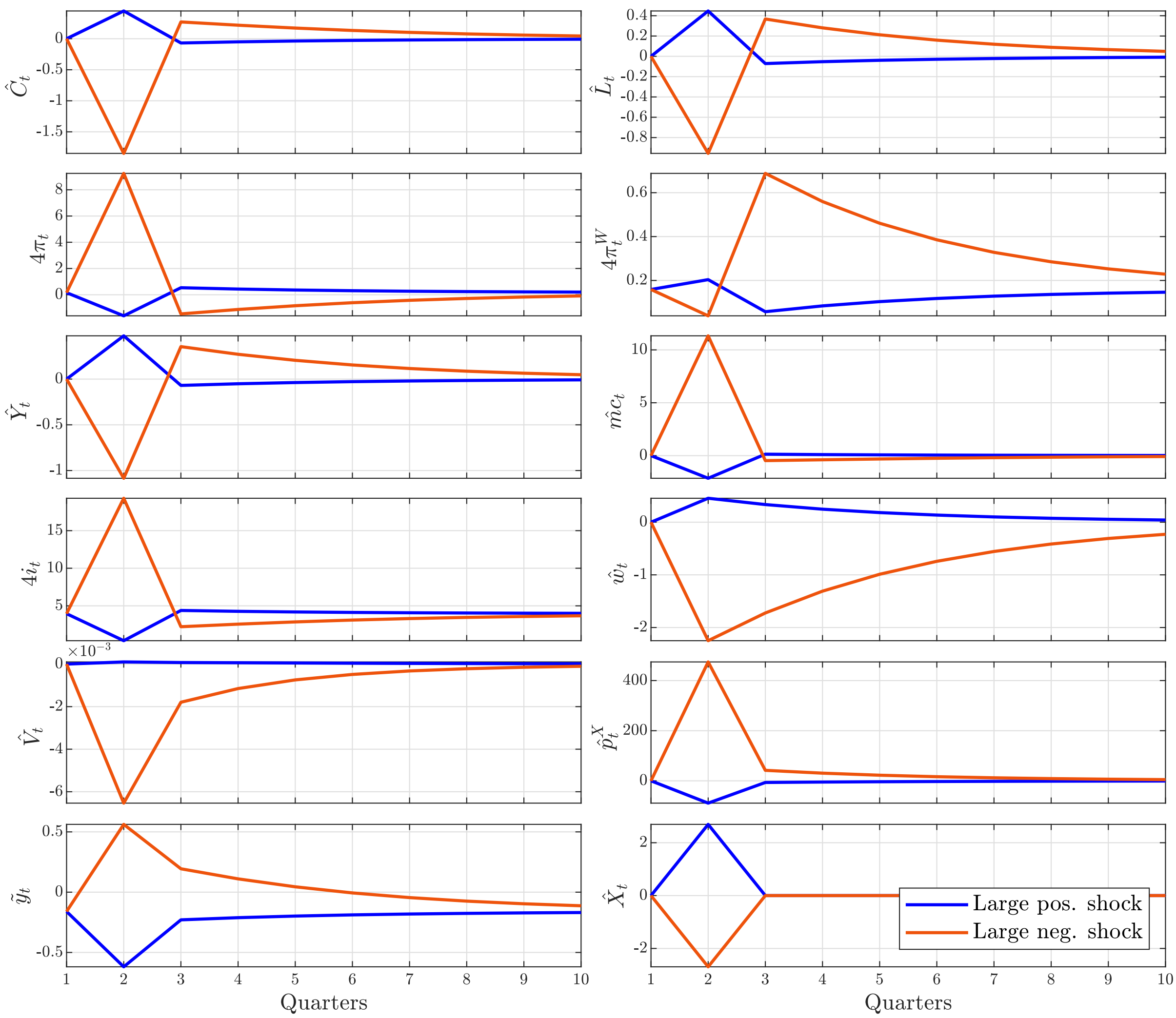

Figure 4.3. Impulse responses functions. Impulse responses to a large negative (red) and large positive (blue) supply shock in baseline economy with a Taylor rule. Hatted variables are denoted in percentage deviations from the stochastic steady state.

4.4 Impulse responses

4.4.1 Positive versus negative supply shocks

Figure 4.3 shows the impulse responses from the nonlinear model to a large positive and a large negative supply shock, respectively. As shown, the responses to positive and negative shocks are highly asymmetric. For instance, a large negative supply shock leads to a large inflation burst. In contrast, a similar-sized positive supply shock does not lead to a large reduction in inflation. This asymmetric response stems from the nonlinear production function. A large negative supply shock drives up marginal costs—and thus inflation—sharply. In contrast, a large positive shock lowers marginal costs, but the effect is noticeably weaker.

While the inflation response in Figure 4.3 is highly asymmetric, the output gap response is nearly symmetric—an implication of a convex price Phillips curve. The large increase in inflation in response to a negative shock implies a sharp reduction in the real wage. Because wages are relatively sticky, the initial inflation burst is followed by a long-lasting period of costly nominal wage adjustment (positive wage inflation).

Figure 4.3 shows that the large negative supply shock leads to a disproportionately large reduction in welfare, as measured by the value function V_t. As the figure shows, consumption and employment increase roughly one-to-one in response to a positive supply shock with nearly no impact on aggregate welfare. In contrast, consumption declines much more than employment in response to a negative shock. Intuitively, large inflation bursts generate menu costs, which lower consumption for given levels of production and employment. These findings imply that policymakers should be more concerned about large negative supply shocks than large positive supply shocks, as the former leads to disproportionately large reductions in welfare.

4.4.2 Small versus large negative supply shocks

Figure 4.4 shows the impulse responses from the nonlinear model to a small versus a large negative supply shock. To highlight the nonlinear effects that arise in response to large shocks, we scale the impulse responses to the small shock by the relative shock size.

As Figure 4.4 shows, the output gap increases slightly more than proportionally in response to the large negative supply shock. But due to the convexity of the price Phillips curve, inflation increases much more than proportionally. Low substitutability of the non-labor input implies that a large negative shock leads to a much larger increase in the input price p_t^X and thus a larger increase in marginal costs. As a result, real wages decline more than proportionally in response to the large shock. Because nominal wages are relatively rigid, it takes a long time for real wages to recover.

Figure 4.4 shows that large negative supply shocks lead to disproportionately large (and persistent) reductions in households' value function V_t. On impact, the large inflation burst generates menu costs, which lead to a sharp reduction in consumption for a given level of employment and production, inducing a substantial welfare loss on impact. This is followed by a long-lasting period of costly nominal wage adjustment, which generates additional welfare losses.

4.4.3 Small versus large positive supply shocks

Figure 4.5 shows the impulse responses to a small versus a large positive supply shock. As before, we scale the impulse responses to the small shock by the relative shock size. As shown, inflation declines *less* than proportionally in response to a large positive supply shock. [TBA]

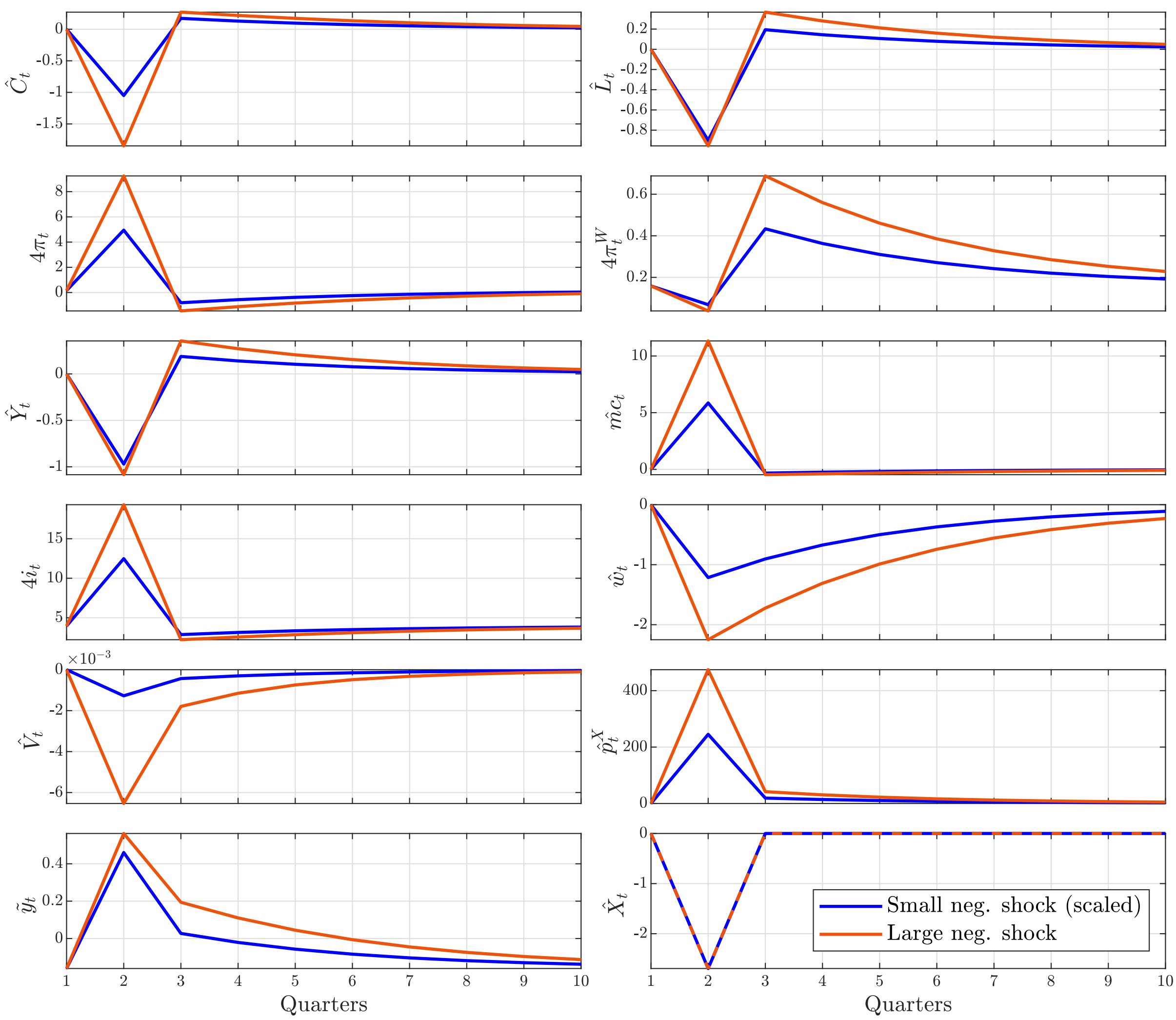

Figure 4.4. Impulse responses functions. Impulse responses to a large negative (red) and small negative (blue) supply shock in baseline economy with a Taylor rule. Hatted variables are denoted in percentage deviations from the stochastic steady state. The IRFs of the small shock are scaled by the relative shock size, with the large shock being three times bigger.

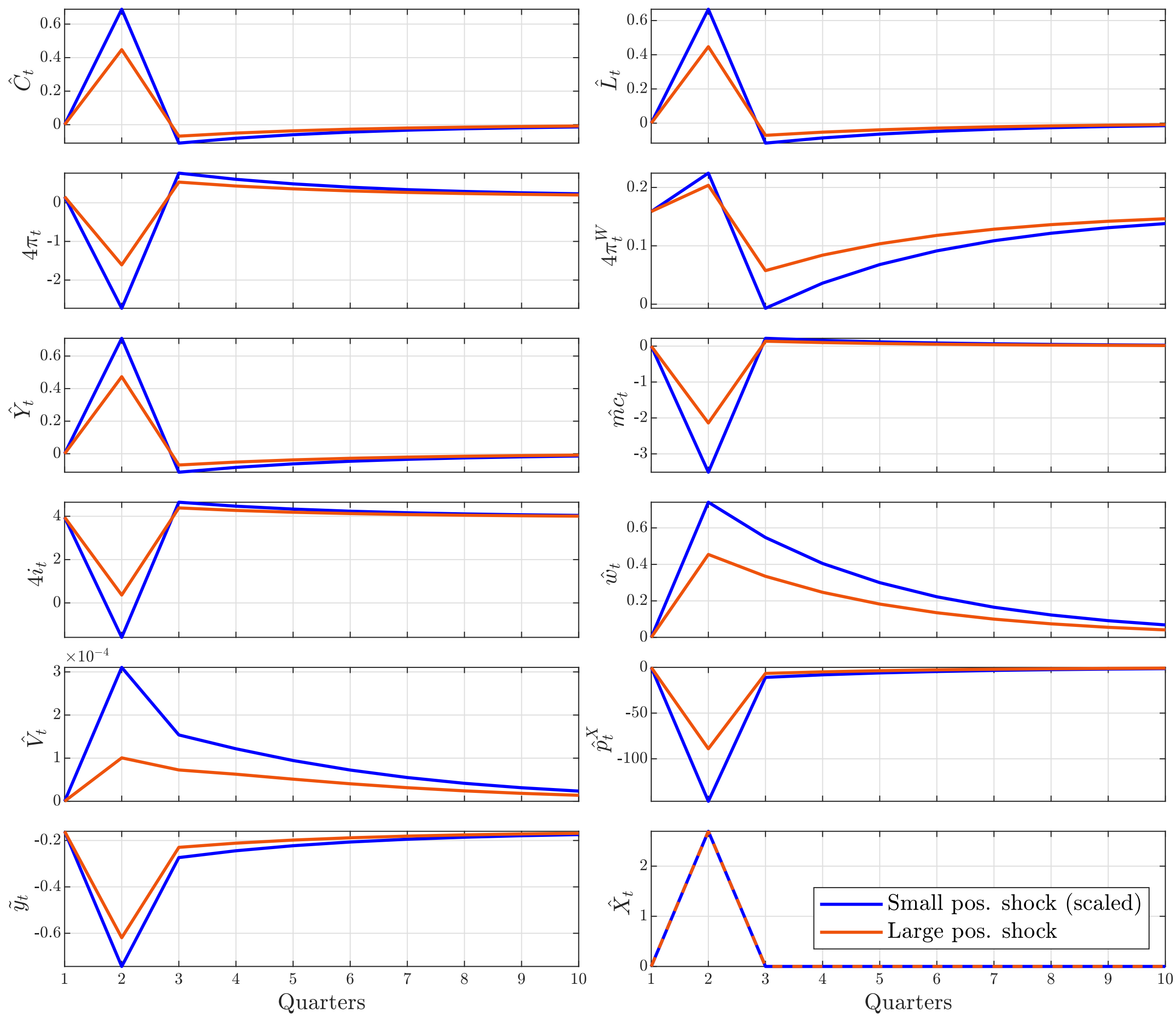

Figure 4.5. Impulse responses functions. Impulse responses to a large positive (red) and small positive (blue) supply shock in baseline economy with a Taylor rule. Hatted variables are denoted in percentage deviations from the stochastic steady state. The IRFs of the small shock are scaled by the relative shock size, with the large shock being three times bigger.

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 resource constraint of the economy (3.14). The complete set of Ramsey equilibrium equations is listed in Appendix B.4.

The state space of the model with a Ramsey planner is too large for a global solution. However, in Appendix C, we show that a fifth-order perturbation approximation is very close to the global solution of 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 Impulse responses with a Ramsey planner

5.2.1 Positive versus negative supply shocks

Figure 5.1 shows the impulse responses to a positive and a negative supply shock, respectively, when monetary policy is conducted by the Ramsey planner. By comparing the impulse responses in Figure 5.1 with the impulse responses from Figure 4.3, we see that the Ramsey planner responds much more strongly to negative shocks than to positive shocks. Specifically, in Figure 5.1, the inflation response to a negative shock is *muted* relative to that of a positive shock—the exact opposite of what we observe in the baseline model with a Taylor rule shown in Figure 4.3. Accordingly, a negative shock leads to a relatively large reduction in the output gap in Figure 5.1, while a positive shock leads to a modest increase in the output gap.

When the central bank contains inflation, the real wage declines much less in response to a negative supply shock. Instead, the responses of the real wage in Figure 5.1 are nearly symmetric. This also means that there is no need for high positive wage inflation in the aftermath of a negative supply shock.

The welfare losses from the negative supply shock are much smaller in Figure 5.1 than in Figure 4.3 with a Taylor rule. Thus, responding aggressively to large negative supply shocks is associated with significant welfare improvements.

The Ramsey planner's systematic asymmetric response to negative vs. positive supply shocks also serves to reduce the *average* level of inflation and raise the *average* level of output in the model, thus correcting the inflation and output gap biases that arise under a standard Taylor rule, as shown in Figure 4.2. In Section 5.2.4, we analyze the welfare gains associated with the Ramsey policy.

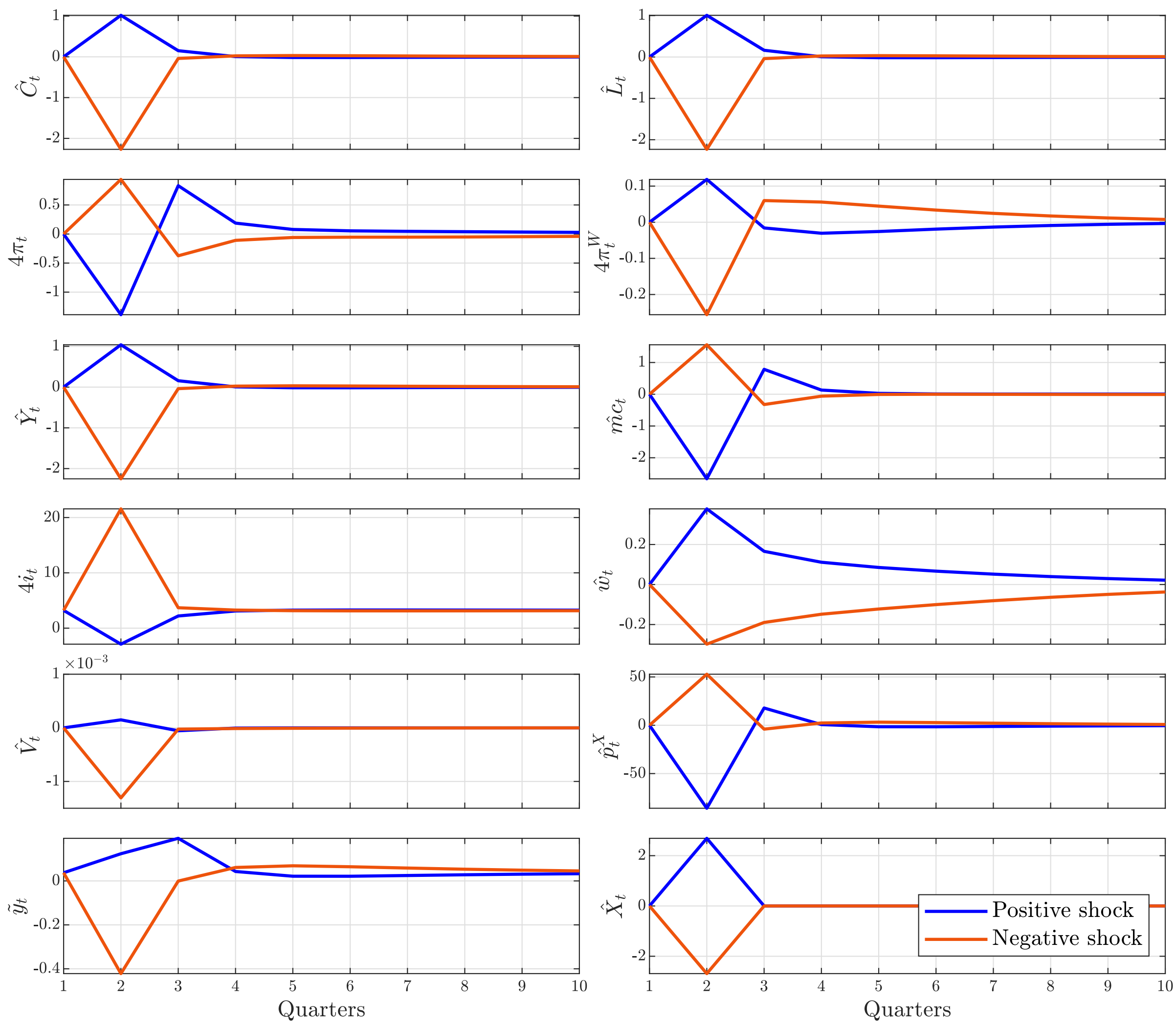

Figure 5.1. Impulse responses functions, Ramsey planner. Impulse responses to a large negative (red) and large positive (blue) supply shock under the Ramsey planner using a fifth-order approximation. Hatted variables are denoted in percentage deviations from the stochastic steady state.

5.2.2 Small versus large negative supply shocks

Figure 5.2 shows the impulse responses to a small versus a large negative supply shock, respectively, with a Ramsey planner. As the figure shows, the responses of inflation and the output gap are nearly proportional to the size of the shock. Thus, the Ramsey planner can almost completely neutralize the nonlinear effects of large negative supply shocks. Intuitively, the convex price Phillips curve is a double-edged sword: If monetary policy responds passively to a large negative supply shock, inflation increases more than proportionally with the shock, inducing large welfare losses.[12] But if monetary policy responds aggressively to inflation, it can facilitate a sizable disinflation without substantially lowering the output gap.

5.2.3 Small versus large positive supply shocks

As Figure 4.5 shows, the convexity of the price Phillips curve entails a relatively muted inflation response to a large positive supply shock under a standard Taylor rule. As a result, the Ramsey planner accommodates large positive supply shocks. As Figure 5.3 shows, the Ramsey planner lowers the interest rate disproportionally in response to the small shock.[13] The sharp reduction in the interest rate serves to raise the output gap and stabilize inflation. As the figure shows, the Ramsey planner does not allow inflation to decline disproportionally in response to the small shock.

5.2.4 Welfare costs of business cycles

TBA

[12]Blanco, Ottonello, and Ranošová (2025) study large inflation surges observed globally over the past three decades. They find that monetary policy tends to underreact to high inflation episodes.

[13]Here we ignore the zero lower bound on the nominal interest rate, hence our nominal rate can be interpreted as a shadow rate, as in Wu and Zhang (2019).

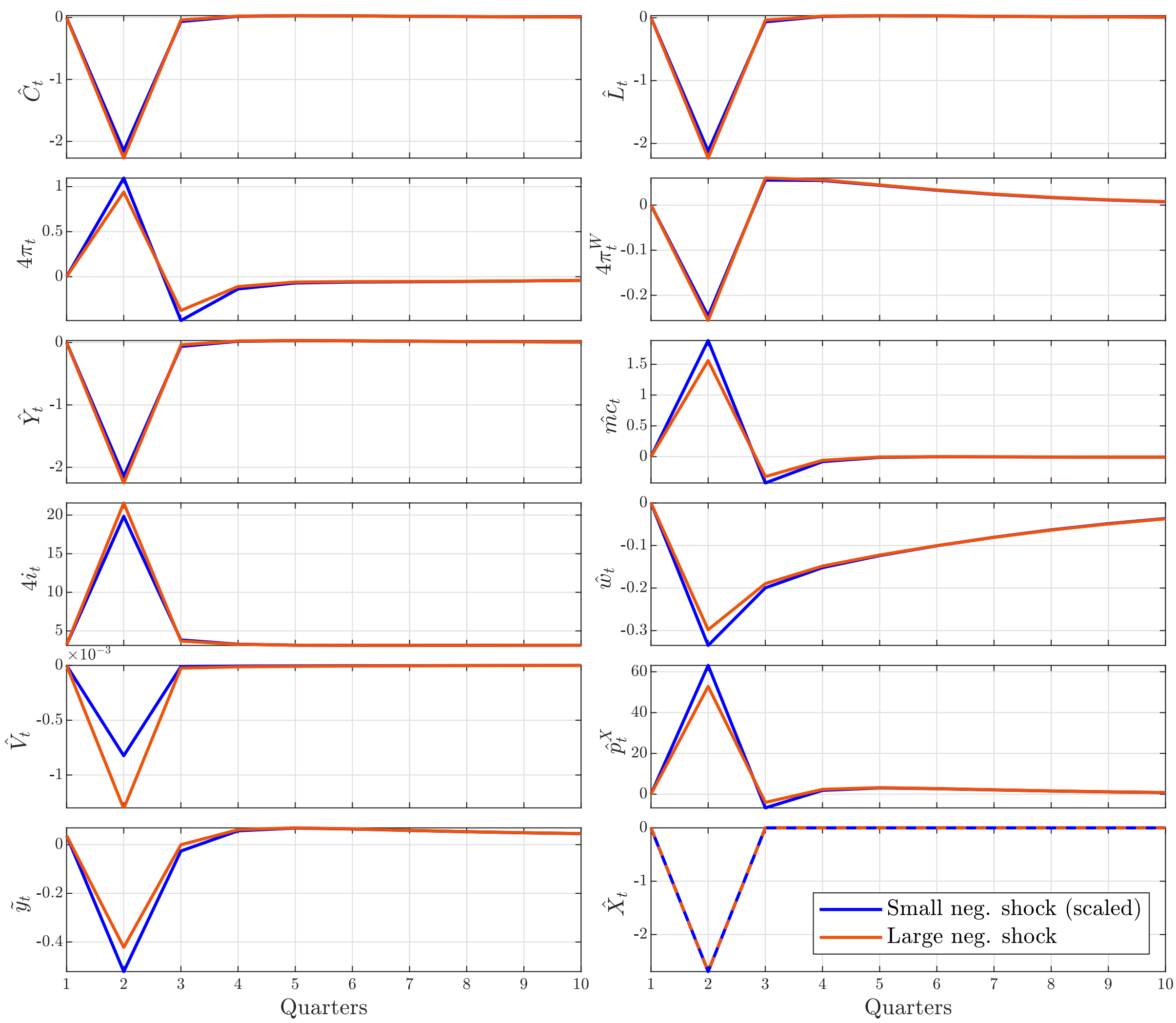

Figure 5.2. Impulse responses functions, Ramsey planner. Impulse responses to a large negative (red) and small negative (blue) supply shock under the Ramsey planner using a fifth-order approximation. Hatted variables are denoted in percentage deviations from the stochastic steady state. The IRFs of the small shock are scaled by the relative shock size, with the large shock being three times bigger.

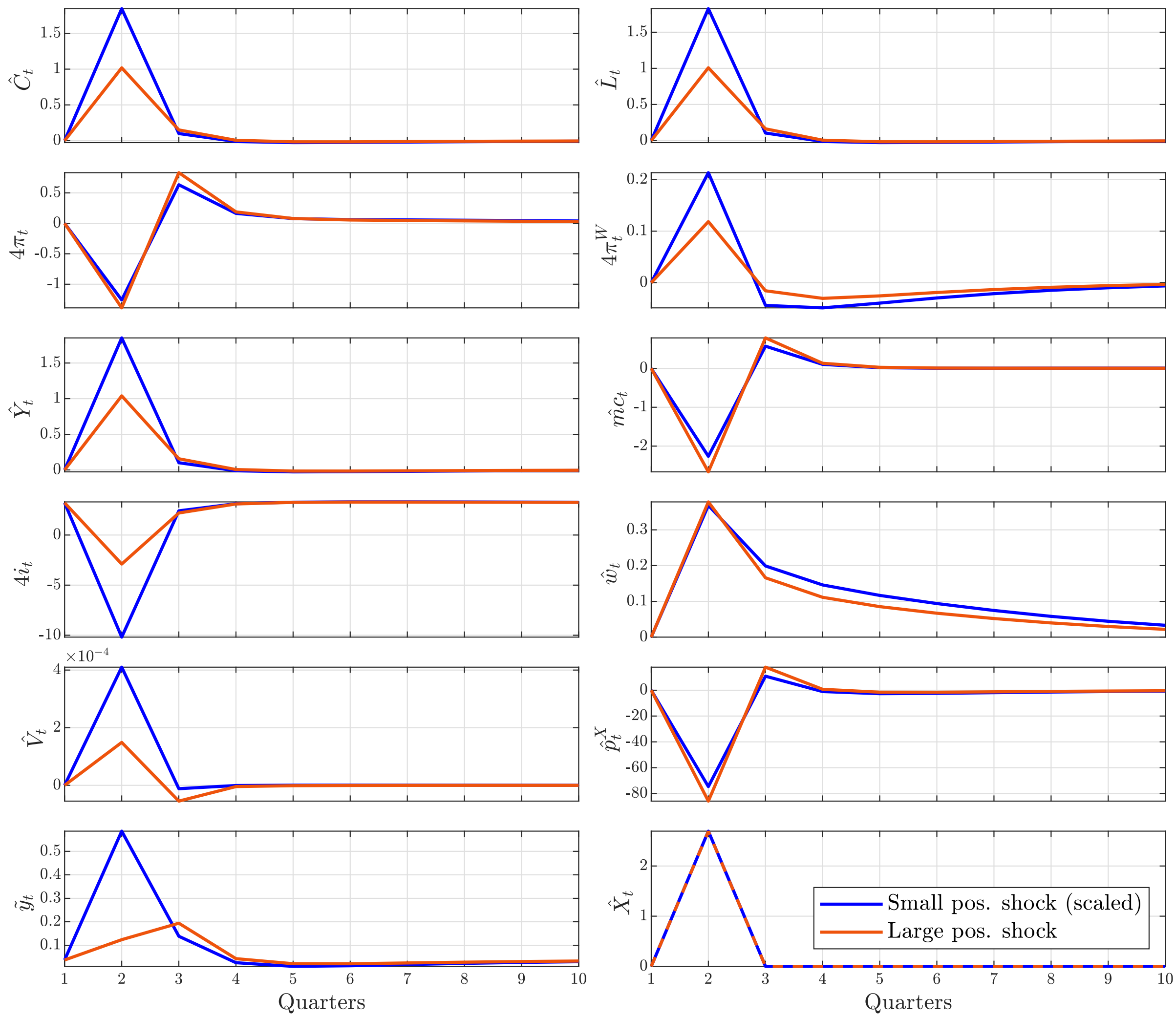

Figure 5.3. Impulse responses functions, Ramsey planner. Impulse responses to a large positive (red) and small positive (blue) supply shock under the Ramsey planner using a fifth-order approximation. Hatted variables are denoted in percentage deviations from the stochastic steady state. The IRFs of the small shock are scaled by the relative shock size, with the large shock being three times bigger.

6. Conclusion

We document a new fact about inflation dynamics in advanced economies. Specifically, we show that inflation displays ”plucking” cycles: A tendency for inflation to rise temporarily above its longer-term trend but rarely drop below it. The plucking property has the following testable implication: Increases in inflation are followed by decreases of similar amplitude, while 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.

To explain the inflation plucking cycles, 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 gives rise to a highly convex price Phillips curve. Negative supply shocks disproportionally raise inflation, while positive supply shocks disproportionally reduce the output gap. As a result, the model 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 efficient level). These level effects—which by construction are absent in linear models—generate substantial welfare losses.

We solve the nonlinear Ramsey problem under commitment. We show that optimal monetary policy in our model responds aggressively to large negative supply shocks while accommodating large positive ones. This policy dampens the inflation plucking cycles, lowers the inflation bias, and raises the average output level, hence yielding sizable welfare gains.

Appendices

A. Data

The data consists of 4-quarter inflation rates from the OECD.[14] Inflation data for most countries covers 1960Q1 to 2024Q2. We consider three samples of data:

- **Full sample:** Using all data avaliable. Applied to our country-specific regressions in Table A.2-A.3.
- **Baseline sample:** For our baseline 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 annual 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 earlier 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 this 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:

- **Inflation increase to decrease:** x_t is the increase amplitude of inflation while y_t is the subsequent decrease amplitude
- **Inflation decrease to increase:** x_t is the decrease amplitude of inflation while y_t is the subsequent increase amplitude

[14] 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	1979Q4-2023Q4	—
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	1999Q4-2024Q2	—
Luxembourg	1960Q1-2024Q2	1960Q1-2024Q2	1986Q4-2024Q2
Mexico	1969Q1-2024Q2	2002Q1-2024Q2	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 countries-specific subsamples used in the empirical analysis.

A.1 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)		

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
Estonia	1998Q1-2024Q2	0.24 (1.89)	1.10* (0.26)	0.82	4	20.80 (8.66)	−1.14 (1.03)	0.23	4
Finland	1960Q1-2024Q2	2.04 (2.26)	0.72* (0.31)	0.37	9	9.13*** (1.83)	−0.36 (0.24)	0.20	9
France	1960Q1-2024Q2	3.77 (2.74)	0.32 (0.44)	0.08	6	6.54* (2.35)	−0.22 (0.35)	0.06	6
Germany	1960Q1-2024Q2	1.37 (1.32)	0.72* (0.29)	0.46	7	4.24 (2.38)	0.17 (0.50)	0.02	7
Greece	1960Q1-2024Q2	4.04** (1.61)	0.54*** (0.14)	0.57	12	12.17** (4.10)	−0.36 (0.39)	0.07	12
Hungary	1981Q1-2024Q2	2.74 (2.78)	0.70** (0.28)	0.39	10	12.30** (3.88)	−0.30 (0.36)	0.07	10
Iceland	1960Q1-2024Q2	2.49 (3.66)	0.83*** (0.17)	0.53	20	13.10*** (4.29)	0.17 (0.19)	0.04	20
Ireland	1976Q1-2024Q2	12.99*** (3.19)	−0.79 (0.45)	0.28	8	5.53* (2.42)	0.14 (0.24)	0.04	8
Israel	1971Q1-2024Q2	−9.02 (5.52)	1.28*** (0.07)	0.96	17	34.73 (20.06)	−0.07 (0.18)	0.01	17
Italy	1960Q1-2024Q2	3.98* (1.74)	0.50** (0.17)	0.52	8	11.95** (4.46)	−0.47 (0.49)	0.10	8
Japan	1960Q1-2021Q2	0.11 (0.63)	1.08*** (0.09)	0.92	11	5.46** (2.01)	−0.06 (0.27)	0.00	11
Latvia	1992Q1-2024Q2	1.68 (5.55)	1.68*** (0.02)	1.00	6	10.87** (3.16)	−0.00 (0.01)	0.05	6
Lithuania	1992Q1-2024Q2	119.53 (111.23)	0.96* (0.45)	0.43	6	12.60 (10.79)	0.03 (0.03)	0.19	6
Luxembourg	1960Q1-2024Q2	−0.83 (2.21)	1.14** (0.35)	0.64	6	7.07** (1.85)	−0.12 (0.28)	0.03	6
Mexico	1969Q1-2024Q2	−1.80 (6.04)	1.09*** (0.12)	0.87	11	29.14* (13.88)	0.04 (0.26)	0.00	11
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.2 Plucking cycles in low-inflation regimes

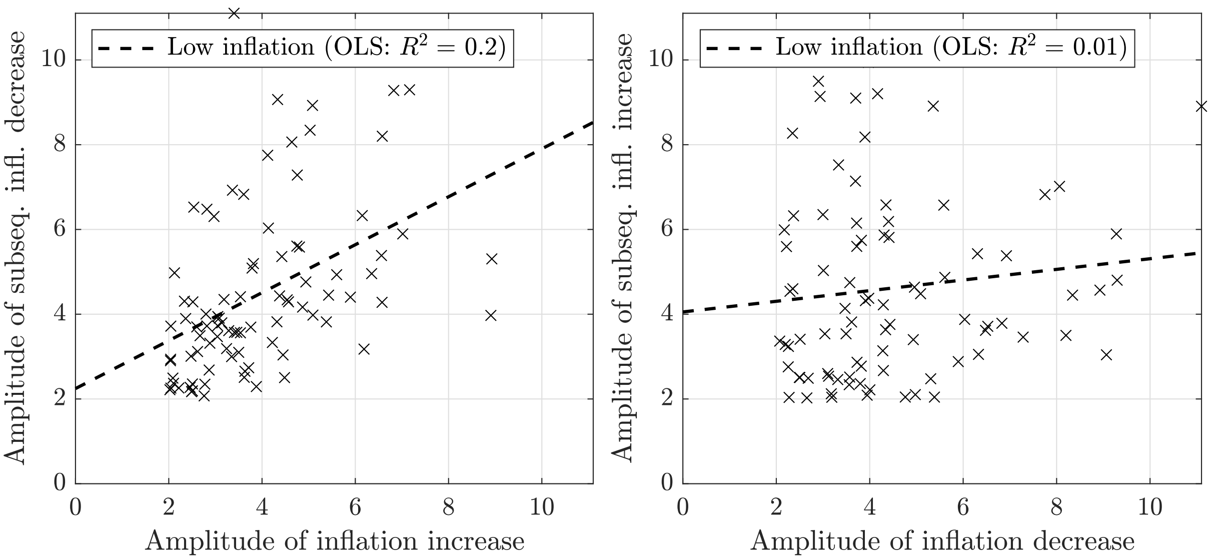

Figure A.1. Inflation plucking cycles in low-inflation regimes. This figure displays scatter plots of amplitudes of inflation cycles for low inflation environments from pooled cross-country OECD observations. The dashed lines are univariate OLS regression lines.

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 observations.

We estimate a version of (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." *, **, and *** denote significance at the 10, 5, and 1 percent levels, respectively.

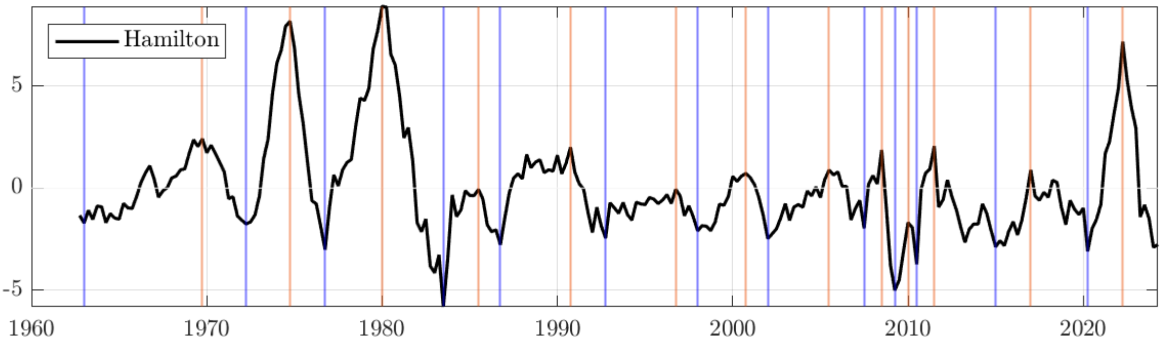

Figure A.2. Inflation This figure displays quarterly US Hamilton-filtered detrended inflation along with marked peaks of inflation (red) and troughs (blue).

A.3 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. 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)	0.67^{***} (0.05)	0.14^{***} (0.05)
R^2	0.85	0.11	0.34	0.02
n	12	12	415	413

Table A.5. Plucking property of de-trended inflation This table reports OLS regression results. *, **, and *** denote significance at the 10, 5, and 1 percent levels, respectively.

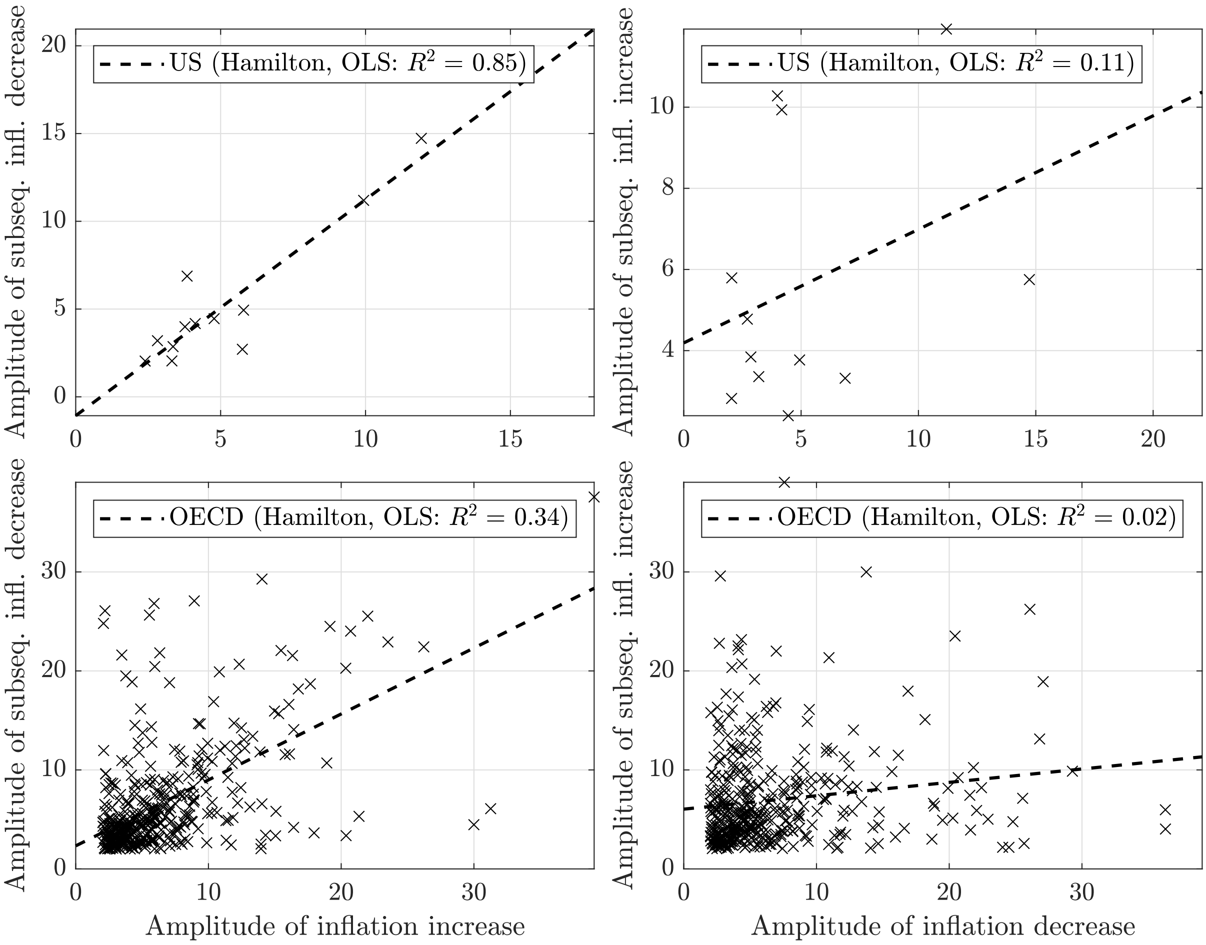

Figure A.3. Inflation plucking cycles (Hamilton filter). This figure displays scatter plots of amplitudes of changes in de-trended inflation rates for the US (upper panels) and the OECD countries (lower panels).

B. Details of the New Keynesian model

B.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

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

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

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

with

$$\frac{\partial L_{jt}}{\partial w_{it}} = -\varepsilon_W \left(w_{jt}/w_t \right)^{-\varepsilon_W - 1} L_t / w_{jt},$$
$$\frac{\partial Y_{jt}^{W}}{\partial w_{it}} = \gamma_W \left(\Pi_t^W - 1 \right) Y_t \Pi_t / w_{jt-1},$$
$$\frac{\partial Y_{jt+1}^{W}}{\partial w_{it}} = -\gamma_W \left(\Pi_{t+1}^W - 1 \right) Y_{t+1} \Pi_t^W / w_{jt},$$
$$\Pi_t^W = \Pi_t w_{jt} / w_{jt-1}.$$

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

B.2 Final goods producers

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

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

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

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

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

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

B.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

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

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

B.4 Ramsey planner

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

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

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 mc_t} \right]^{-\phi} Y_{Lt} - 1 \right] + \mu_{5t} \left[\left[\frac{p_t^X}{mc_t (1-\alpha)} \right]^{-\phi} Y_{Lt} \right] + \mu_{6t} \left[1 - Y_{Yt}^P - 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[Y_{\Pi t}^P + 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 mc_t} \right]^{-\phi} Y_{Xt} \right] + \mu_{5t} \left[\left[\frac{p_t^X}{mc_t (1-\alpha)} \right]^{-\phi} Y_{Xt} - 1 \right] + \mu_{6t} \left[1 - Y_{Yt}^P - Y_{Yt}^W \right] Y_{Xt} = 0,
\end{aligned}
$$

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

The above derivatives are defined below

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

B.5 Proof of proposition 1

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

$$
L_i = \left[\frac{w_i}{\alpha mc_i}\right]^{-\phi} Y_i.
$$

Isolating for marginal costs and $\phi \to 0$ gives the following expression

$$
mc_i = \lim_{\phi \to 0}\left(\frac{L_i}{Y_i}\right)^{\phi^{-1}}\frac{w_i}{\alpha}.
$$

By applying the properties of limits, we obtain

$$mc_i = \lim_{\phi \to 0} \left[\frac{L_i}{\lim_{\phi \to 0} \left(\alpha L_i^{\frac{\phi-1}{\phi}} + (1-\alpha) X_i^{\frac{\phi-1}{\phi}} \right)^{\frac{\phi}{\phi-1}}} \right]^{\phi^{-1}} \frac{w_i}{\alpha},$$

which we can rewrite to (as $\lim_{\phi \to 0} Y_i = \min \{X_i, L_i\}$, see Lemma 2)

$$mc_i = \lim_{\phi \to 0} \left(\frac{L_i}{\min \{X_i, L_i\}} \right)^{\phi^{-1}} \frac{w_i}{\alpha}.$$

Two cases arise. Either $\min \{X_i, L_i\} = L_i$ and mc_i equals $\frac{w_i}{\alpha}$, or $\min \{X_i, L_i\} = X_i$, and the marginal costs tend to infinity. ■

Lemma 2. ***Leontief production function.*** *As* $\phi \to 0$*, the production function in* (3.7) *becomes*

$$Y_i = \min \{X_i, L_i\}.$$

Proof. We start by rewriting the production function to

$$Y_i = \exp \left\{ -\frac{\log \left\{ \left(\alpha L_i^{-\rho} + (1-\alpha) X_i^{-\rho} \right) \right\}}{\rho} \right\}.$$

where $\rho = \phi^{-1} - 1$. Letting $\rho \to \infty$ while applying L'Hopital's rule yield

$$\lim_{\rho \to \infty} Y_i = \exp \left\{ \lim_{\rho \to \infty} \frac{\alpha L_i^{-\rho} \log (L_i) + (1-\alpha) X_i^{-\rho} \log (X_i)}{\alpha L_i^{-\rho} + (1-\alpha) X_i^{-\rho}} \right\}.$$

Now, define the auxiliary variables $y_i = \min \{X_i, L_i\}$, $v_X = X_i / y_i \leq 1.$ and $v_L = L_i / y_i \leq 1$. Then, we extend the fraction by y_i^{ρ}

$$\begin{aligned} \lim_{\rho \to \infty} Y_i &= \exp \left\{ \lim_{\rho \to \infty} \frac{\alpha L_i^{-\rho} y_i^{\rho} \log (L_i) + (1-\alpha) X_i^{-\rho} y_i^{\rho} \log (X_i)}{\alpha L_i^{-\rho} y_i^{\rho} + (1-\alpha) X_i^{-\rho} y_i^{\rho}} \right\}, \\ &= \exp \left\{ \lim_{\rho \to \infty} \frac{\alpha v_L^{-\rho} \log (L_i) + (1-\alpha) v_X^{-\rho} \log (X_i)}{\alpha v_L^{-\rho} + (1-\alpha) v_X^{-\rho}} \right\}, \end{aligned}$$

We therefore have our desired result

$$\lim_{\rho \to \infty} Y_i = \begin{cases} X_i & \text{if } X_i < L_i, \\ L_i & \text{if } L_i < X_i, \end{cases}$$

which proves the lemma. ■

C. Computational algorithm

C.1 Time-iteration

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 $\varepsilon_t^i \in \boldsymbol{\varepsilon^i} = [\varepsilon_{min}^i, \ldots, \varepsilon_{max}^i]^{\intercal}$ 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 $L_t(\boldsymbol{w}\boldsymbol{z}^{\intercal}), \Pi_t(\boldsymbol{w}\boldsymbol{z}^{\intercal})$, and $\Pi_t^W(\boldsymbol{w}\boldsymbol{z}^{\intercal})$ 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 $\circ$)

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

   which allows us to obtain estimates on

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

   using interpolation.

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

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

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

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

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

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

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

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

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

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

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

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

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

with

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

7. If

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

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

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

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

C.2 Accuracy of perturbation

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

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

where U^{pa} is a perturbation approximation of the per-period utility, and U is its exact value from the global solution. Intuitively, E has the interpretation of percentage deviations from the true utility. Table C.1 summarizes the error measures for rising orders of perturbation approximations. As the order rises, the approximation error—in terms of percent deviations of per-period utility—strictly declines.

Perturbation	First order	Second order	Third order	Fourth order	Fifth order
Mean of E	0.046	0.024	0.019	0.013	0.012

Table C.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 C.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 C.1, the fifth-order approximation is highly accurate, even for a large negative supply shock.

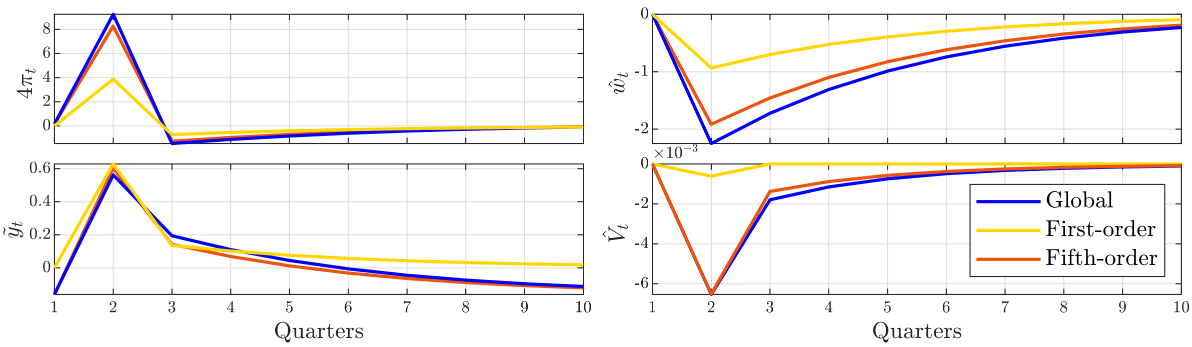

Figure C.1. Impulse responses functions. Impulse responses to a large negative shock using a global (blue), Dynare's first-order (yellow), and fifth-order (red) solution. Hatted variables are denoted in percentage deviations from the stochastic steady state.

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