The Inflation Accelerator

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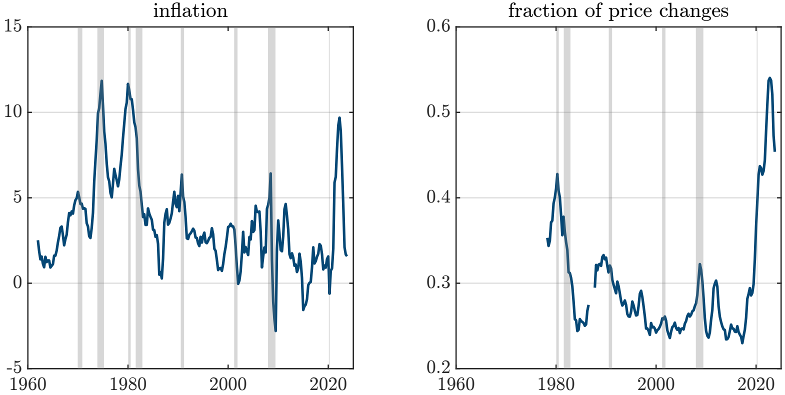
[1] The views expressed herein are those of the authors and not necessarily those of the Board of Governors of the Federal Reserve System, the Federal Reserve Bank of Atlanta or the Federal Reserve System.

Motivation

- Slope of Phillips curve crucial ingredient in monetary policy analysis
  - governs tradeoff between inflation and output stabilization
- In sticky price models pinned down by fraction of price changes
- Data: fraction of price changes increases with inflation

Evidence from the U.S.



- Source: Nakamura et al. (2018), Montag and Villar (2023)

Motivation

- Slope of Phillips curve crucial ingredient in monetary policy analysis
  - governs tradeoff between inflation and output stabilization
- In sticky price models, key determinant: fraction of price changes
- Data: fraction of price changes increases with inflation
- How does the slope of the Phillips fluctuate in U.S. time series?
  - answer using model that reproduces this evidence

Existing Models

- Time-dependent models (e.g. Calvo)
  - widely used due to their tractability
  - constant fraction of price changes

- State-dependent models (e.g. menu cost)
  - less tractable: state of the economy includes distribution of prices

- We develop tractable alternative with endogenously varying fraction
  - multi-product firms choose *how many*, but not *which*, prices to change
  - exact aggregation: reduces to one-equation extension of Calvo

Our Findings

- Our model predicts highly non-linear Phillips curve
  - slope fluctuates from 0.02 in 1990s to 0.12 in 1970s and 1980s

- Mostly due to feedback loop between fraction and inflation

  inflation accelerator

  - higher inflation increases fraction of price changes
  - higher fraction of price changes further increases inflation
  - absent *inflation accelerator* slope increases to 0.04 in 1970s and 1980s

- Sacrifice ratio in last inflation surge: $\approx 1/3$ relative to the 1990s

Model

Environment

- Agents: A household & final good firm, intermediate good firms i
  - intermediate good firms sell continuum of goods k each [multi-product]
- Preference: $\mathbb{E}_t \sum_{t=0}^{\infty} \beta^t (\log c_t - h_t)$
  + cash-in-advance constraint implies $W_t = P_t c_t = M_t$
  - money growth: $\log M_{t+1}/M_t = \mu + \sigma \varepsilon_{t+1}$ (only aggregate shock)
- Technology final good firm: $y_t = \left(\int_0^1 \int_0^1 (y_{ikt})^{\frac{\theta-1}{\theta}} \, \mathrm{d}k\mathrm{d}i \right)^{\frac{\theta}{\theta-1}}$
  - demand for individual variety: $y_{ikt} = \left(\frac{P_{ikt}}{P_t} \right)^{-\theta} y_t$
- Technology firm i product k: $y_{ikt} = (l_{ikt})^{\eta}$
  - $\eta \leq 1$: micro-strategic complementarities in price setting
- Feasibility: $c_t = y_t$

Multi-product Firms Problem

- Price adjustment cost in labor units: $F(n_{ti}) = \xi \left(n_{it} - \bar{n}\right)^2/2$ if $n_{it} > \bar{n}$
  - firm chooses fraction of prices to change but not which

- Real profits:

$$\frac{\int_0^1 (P_{ikt} y_{ikt} - \tau W_t l_{ikt}) \mathrm{d}k - W_t F(n_{ti})}{P_t}$$

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$$\frac{\int_0^1 (P_{ikt} y_{ikt} - \tau W_t l_{ikt}) \mathrm{d}k}{P_t} = \left(\frac{P_{it}}{P_t}\right)^{1-\theta} y_t - \tau \left(\frac{X_{it}}{P_t}\right)^{-\frac{\theta}{\eta}} y_t^{\frac{1}{\eta}+1}$$

  - firm i price index: $P_{it} = \left(\int_0^1 \left(P_{ikt}\right)^{1-\theta} \mathrm{d}k\right)^{\frac{1}{1-\theta}}$
  - firm i within misallocation: $X_{it} = \left(\int_0^1 \left(P_{ikt}\right)^{-\frac{\theta}{\eta}} \mathrm{d}k\right)^{-\frac{\eta}{\theta}}$, $X_t / P_t < 1$

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- Firm chooses P_{it}^* and n_{it} to maximize expected discounted profits
- Result: Firm i idiosyncratic state variables are P_{it-1} and X_{it-1}
  - e.g. $P_{it} = \left(n_{it}\left(P_{it}^*\right)^{1-\theta} + \left(1 - n_{it}\right)\left(P_{it-1}\right)^{1-\theta}\right)^{\frac{1}{1-\theta}}$
- Since firms are identical: $P_t^* = P_{it}^*$, $X_t = X_{it}$, and $n_t = n_{it}$

Firms Optimal Decision

- Optimal reset price: $p_t^* = P_t^*/P_t$ [similar to Calvo but time-varying n_t]

$$\left(p_t^*\right)^{1+\theta\left(\frac{1}{\eta}-1\right)} = \frac{\left.\mathbb{E}_t \sum_{s=0}^{\infty} \beta^s \prod_{j=1}^{s} \left(1 - n_{t+j}\right) \pi_{t+j}^{\theta/\eta} mc_{t+s} \right\} b_{2t}}{\left.\mathbb{E}_t \sum_{s=0}^{\infty} \beta^s \prod_{j=1}^{s} \left(1 - n_{t+j}\right) \pi_{t+j}^{\theta-1} \right\} b_{1t}}$$

  – inflation: $\pi_t = P_t/P_{t-1}$

  – real marginal cost: $mc_t = w_t y_t^{1/\eta-1}/\eta = y_t^{1/\eta}/\eta$

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$$

  - inflation: $\pi_t = P_t/P_{t-1}$
  - real marginal cost: $mc_t = w_t y_t^{1/\eta-1}/\eta = y_t^{1/\eta}/\eta$

- Fraction of price changes [case $\beta = 0$]

$$
y_t \xi (n_t - \bar{n}) = \underbrace{\left((p_t^*)^{1-\theta} - \left(\frac{P_{it-1}}{P_t}\right)^{1-\theta} \right) y_t}_{\text{change in revenue}} - \underbrace{\tau y_t^{1/\eta+1} \left((p_t^*)^{-\frac{\theta}{\eta}} - \left(\frac{X_{it-1}}{P_t}\right)^{-\frac{\theta}{\eta}} \right)}_{\text{change in cost [}\Downarrow\text{ misallocation]}}
$$

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$$\xi\left(n_t - \bar{n}\right) = \underbrace{\left(\left(p_t^*\right)^{1-\theta} - \left(\pi_t\right)^{\theta-1}\right)}_{\text{change in revenue}} - \underbrace{\tau y_t^{1/\eta}\left(\left(p_t^*\right)^{-\frac{\theta}{\eta}} - \left(x_{t-1}\right)^{-\frac{\theta}{\eta}}\left(\pi_t\right)^{\frac{\theta}{\eta}}\right)}_{\text{change in cost } [\Downarrow \text{ misallocation}]}$$

  - misallocation: $x_t = X_t/P_t$

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  - real marginal cost: $mc_t = w_t y_t^{1/\eta-1}/\eta = y_t^{1/\eta}/\eta$

- Fraction of price changes

$$\xi\left(n_t - \bar{n}\right) = \underbrace{b_{1t}\left(\left(p_t^*\right)^{1-\theta} - \left(\pi_t\right)^{\theta-1}\right)}_{\text{PDV of change in revenue}} - \underbrace{\tau\eta b_{2t}\left(\left(p_t^*\right)^{-\frac{\theta}{\eta}} - \left(x_{t-1}\right)^{-\frac{\theta}{\eta}}\left(\pi_t\right)^{\frac{\theta}{\eta}}\right)}_{\text{PDV of change in cost [}\Downarrow\text{ misallocation]}}$$

  - misallocation: $x_t = X_t/P_t$

Aggregation

- Inflation pinned down by the definition of price index

$$1 = n_t \left(p_t^*\right)^{1-\theta} + (1 - n_t) \left(\pi_t\right)^{\theta-1}$$

- Losses from misallocation

$$\left(x_t\right)^{-\frac{\theta}{\eta}} = n_t \left(p_t^*\right)^{-\frac{\theta}{\eta}} + (1 - n_t) \left(x_{t-1}\right)^{-\frac{\theta}{\eta}} \left(\pi_t\right)^{\frac{\theta}{\eta}}$$

- Model reduces to one-equation extension of Calvo
  - as $\xi \to \infty$, $n_t = \bar{n}$ so our model nests Calvo

Phillips Curve in the Time-Series

Parameterization

- Assigned parameters
  - period 1 quarter, $\beta = 0.99$, $\theta = 6$, $\eta = 2/3$

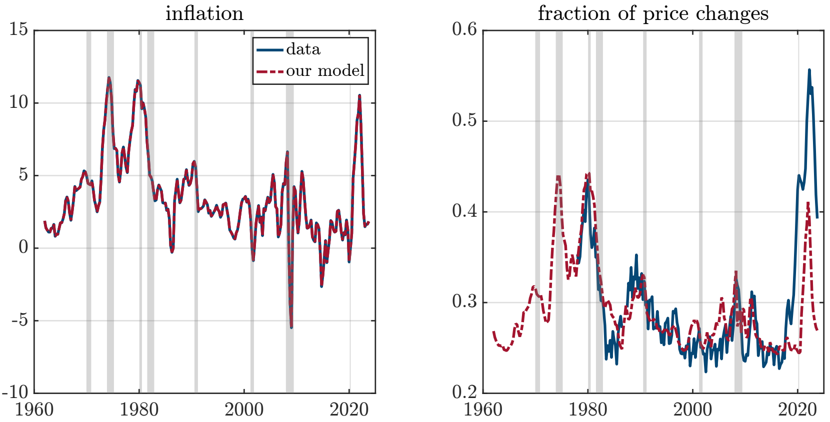
- Calibrated parameters
  - mean and standard deviation of money growth μ and σ
  - fraction of free price changes $\bar{n}$, price adjustment cost ξ

- Calibration targets

	Data	Model
mean inflation	0.035	0.035
s.d. inflation	0.027	0.027
mean fraction	0.297	0.297
slope of n_t on $\lvert\pi_t\rvert$	0.016	0.016

Fraction of Price Changes

- Use non-linear solution to recover shocks that reproduce U.S. inflation



Towards the Slope of the Phillips Curve

- First order perturbation around equilibrium point at each date t
  - hats denote deviations from equilibrium at that date

- Aggregate price index: $1 = n_t \left(p_t^*\right)^{1-\theta} + (1 - n_t)\left(\pi_t\right)^{\theta-1}$

$$\hat{\pi}_t = \underbrace{\frac{1}{(1-n_t)\,\pi_t^{\theta-1}} \frac{\pi_t^{\theta-1}-1}{\theta-1}}_{=\mathcal{M}_t} \hat{n}_t + \underbrace{\frac{1-(1-n_t)\,\pi_t^{\theta-1}}{(1-n_t)\,\pi_t^{\theta-1}}}_{=\mathcal{N}_t} \hat{p}_t^*$$

- Elasticity $\mathcal{N}_t$ to reset price: similar to Calvo but with varying n_t
  - increases with n_t, decreases with π_t (lower weight on new prices)

- Elasticity $\mathcal{M}_t$ to frequency: zero if $\pi_t = 1$, increases with inflation

Intuition

- Why is inflation more sensitive to changes in n_t when inflation is high?

$$\mathcal{M}_t = \frac{1}{(1-n_t)\,\pi_t^{\theta-1}} \frac{\pi_t^{\theta-1}-1}{\theta-1}$$

- Inflation $\approx$ average price change $\times$ fraction of price changes
  - $\pi_t = 1$: average price change $= 0$
    - so fraction inconsequential
  - π_t is high: average price change is large
    - so Δn_t increases inflation considerably
  - similar intuition as Caplin and Spulber (1987)

Inflation Accelerator

- Recall aggregate price index

$$\hat{\pi}_t = \mathcal{M}_t \hat{n}_t + \mathcal{N}_t \hat{p}_t^*$$

  - elasticity $\mathcal{M}_t$ increases with inflation, zero if $\pi_t = 1$

- Optimal fraction of price changes

$$\hat{n}_t = \mathcal{A}_t \hat{\pi}_t + \mathcal{B}_t \hat{p}_t^* - \mathcal{C}_t \hat{x}_{t-1} + \frac{n_t - \bar{n}}{n_t} \hat{b}_{1t}$$

  - elasticities $\mathcal{A}_t$ and $\mathcal{B}_t$ also increase with π_t

- Feedback loop amplifies inflation response to changes in reset price

$$\hat{\pi}_t = \frac{\mathcal{M}_t \mathcal{B}_t + \mathcal{N}_t}{1 - \mathcal{M}_t \mathcal{A}_t} \hat{p}_t^* - \frac{\mathcal{M}_t \mathcal{C}_t}{1 - \mathcal{M}_t \mathcal{A}_t} \hat{x}_{t-1} + \frac{\mathcal{M}_t}{1 - \mathcal{M}_t \mathcal{A}_t} \frac{n_t - \bar{n}}{n_t} \hat{b}_{1t}$$

Slope of the Phillips Curve

- Let $\widehat{mc}_t = \frac{1}{\eta}\hat{y}_t$ aggregate real marginal cost

$$\hat{\pi}_t = \mathcal{K}_t \widehat{mc}_t + \dots$$

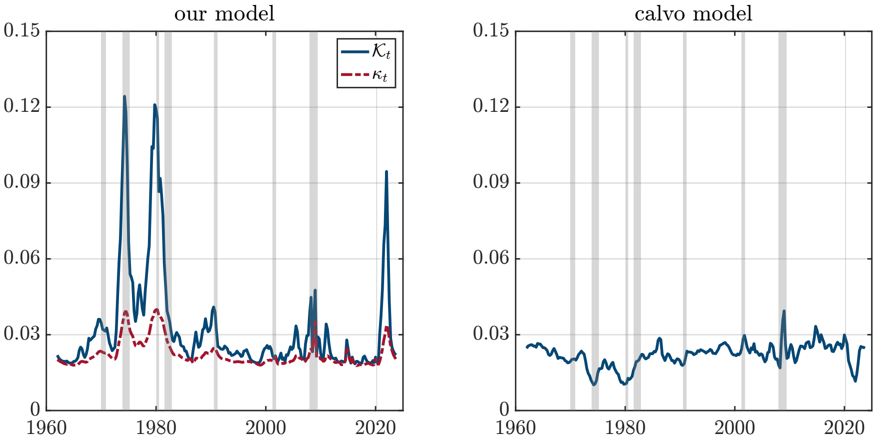
- Slope of the Phillips curve

$$\mathcal{K}_t = \underbrace{\frac{y_t^{\frac{1}{\eta}}}{b_{2t}}}_{\text{horizon}} \times \underbrace{\frac{1}{1+\theta\left(\frac{1}{\eta}-1\right)}}_{\text{complementarities}} \times \underbrace{\frac{\mathcal{M}_t\mathcal{B}_t + \mathcal{N}_t}{1-\mathcal{M}_t\mathcal{A}_t}}_{\text{reset price}}$$

- Absent endogenous frequency response ($\mathcal{A}_t = \mathcal{B}_t = 0$)

$$\kappa_t = \frac{y_t^{\frac{1}{\eta}}}{b_{2t}} \times \frac{1}{1+\theta\left(\frac{1}{\eta}-1\right)} \times \underbrace{\frac{1-(1-n_t)\,\pi_t^{\theta-1}}{(1-n_t)\,\pi_t^{\theta-1}}}_{\mathcal{N}_t}$$

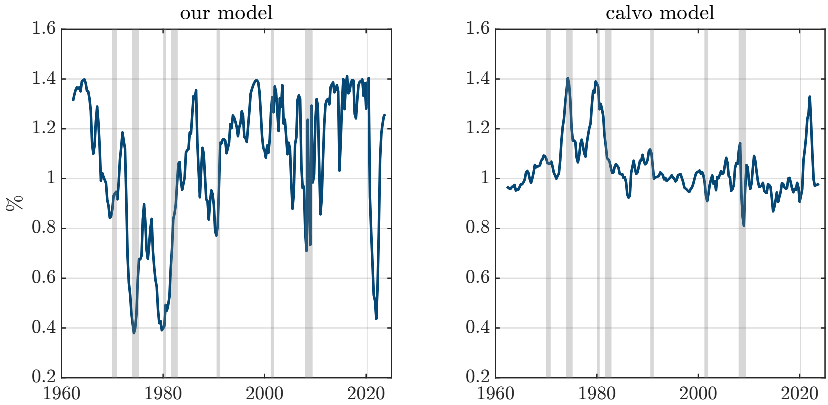
Time-Varying Slope of the Phillips Curve



Ranges from 0.02 to 0.12, mostly due to inflation accelerator

Sacrifice Ratio

- Calculate decline in annual output needed to reduce π by 1% over a year



Ranges from 0.4% to 1.4%, opposite of Calvo

Conclusion

- Data: fraction of price changes increases with inflation

- Developed tractable model consistent with this evidence
  - firms choose how many, but not which prices to change
  - reduces to one-equation extension of Calvo

- Implies slope of Phillips curve increases considerably with inflation
  - partly because more frequent price changes
  - primarily due to endogenous frequency response – *inflation accelerator*

Extensions

Three Practical Extensions

1. Idiosyncratic shocks
   – to match distribution of micro price changes

2. Taylor rule for monetary policy
   – standard in NK models

3. Multiple aggregate shocks
   – to study drivers of inflation

- Robustness: the role of strategic complementarities

▸ $\eta = 1$

Idiosyncratic Shocks

- Individual goods produced with technology

$$y_{ikt} = z_{ikt} l_{ikt}^{\eta}, \quad \text{where} \quad \log z_{ikt} = \log z_{ikt-1} + \sigma_z \epsilon_{ikt}, \; \epsilon_{ikt} \sim N(0,1)$$

- Final output

$$y_t = \left(\int_0^1 \int_0^1 \left(\frac{y_{ikt}}{z_{ikt}} \right)^{\frac{\theta-1}{\theta}} \mathrm{d}k \mathrm{d}i \right)^{\frac{\theta}{\theta-1}}$$

- Firm price index P_{it} and misallocation X_{it} depend on $z_{ikt} P_{ikt}$

- Expressions similar to benchmark, with scaling terms that depend on σ_z
  - e.g., terms involving $\pi_t^{\theta-1}$ scaled by $\exp\left(\frac{\sigma_z^2}{2}(1-\theta)^2\right)$

Calibration

- Because idiosyncratic shocks motive to change prices, assume $\bar{n} = 0$

A. Targeted Moments

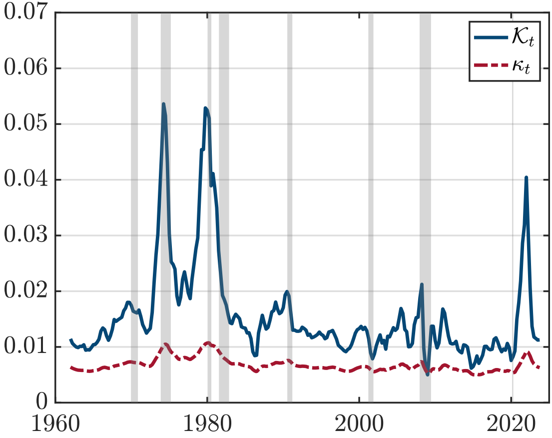
	Data	Model
mean inflation	3.517	3.517
s.d. inflation	2.739	2.739
mean frequency	0.297	0.297
slope of n_t on $\lvert\pi_t\rvert$	0.016	0.015
s.d. price changes	0.129	0.129

B. Calibrated Parameter Values

		Model
μ	mean spending growth rate	0.035
σ	s.d. monetary shocks	0.023
ξ	adjustment cost	17.00
σ_z	s.d. idiosyncratic shocks	0.068

Note: The mean nominal spending growth rate is annualized. S.d. of price changes is from Morales-Jimenez-Stevens (2024).

Slope of the Phillips Curve



Smaller with idiosyncratic shocks, but fluctuates as much

Taylor Rule

- Replace nominal spending target with Taylor rule

$$\frac{1+i_t}{1+i} = \left(\frac{1+i_{t-1}}{1+i}\right)^{\phi_i} \left(\left(\frac{\pi_t}{\pi}\right)^{\phi_\pi} \left(\frac{y_t}{y_{t-1}}\right)^{\phi_y}\right)^{1-\phi_i} \exp\left(u_t\right)$$

- Two versions
  - u_t shocks iid
  - serially correlated with persistence ρ to match autocorrelation inflation

- Use Justiniano-Primiceri (2008) estimates
  - $\phi_i = 0.65$, $\phi_\pi = 2.35$, $\phi_y = 0.51$

Calibration of Economy with a Taylor Rule

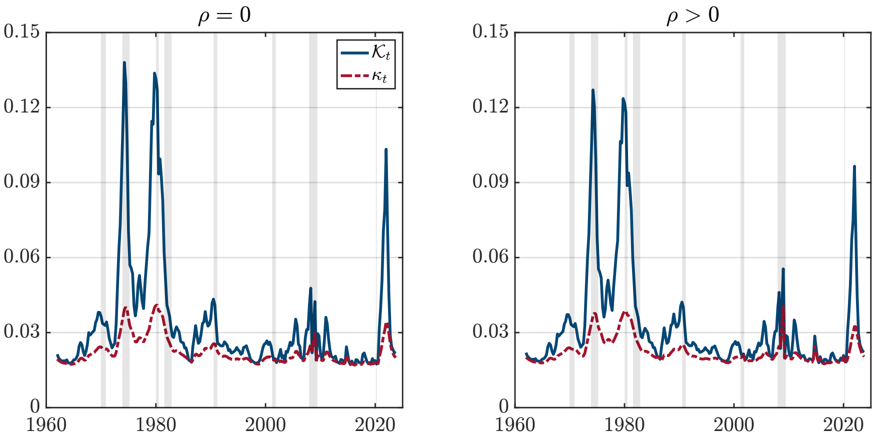
Targeted Moments

	Data	$\rho = 0$	$\rho > 0$
mean inflation	3.517	3.517	3.517
s.d. inflation	2.739	2.739	2.739
mean frequency	0.297	0.297	0.297
slope of n_t on $\vert\pi_t\vert$	0.016	0.016	0.016
autocorr. inflation	0.942	*0.913*	0.942

Calibrated Parameters

		$\rho = 0$	$\rho > 0$
$\log \pi$	inflation target	0.040	0.037
σ	s.d. monetary shocks $\times 100$	2.626	0.551
ρ	persistence monetary shocks	–	0.685
$\bar{n}$	fraction free price changes	0.241	0.241
ξ	adjustment cost	1.671	1.688

Slope of the Phillips Curve



Results are robust to assuming a Taylor rule

Additional Aggregate Shocks

- Three sources of aggregate uncertainty, all follow AR(1)
  - aggregate productivity shocks

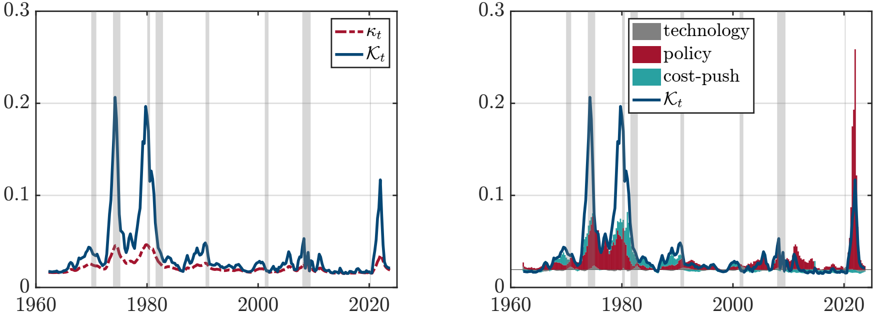
    $$y_{ikt} = z_t l_{ikt}^{\eta}$$

  - time-varying tax on labor (cost-push shock)

    $$P_{ikt} y_{ikt} - \tau_t W_t l_{ikt}$$

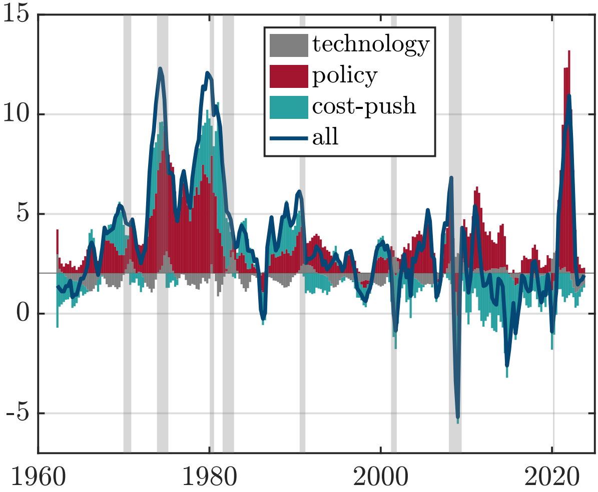
  - interest rate shocks in Taylor rule
- Bayesian estimation, as typical in NK literature
- Back out productivity, cost-push and monetary shocks
  - so that model matches path of inflation, output growth and interest rate
- Compute slope of Phillips curve as in bechmark

Slope of the Phillips Curve



Results are robust to adding multiple aggregate shocks

Causes of Inflation



Losses from Misallocation

$$(X_{it+s})^{-\frac{\theta}{\eta}} = n_{it+s}\left(P^*_{it+s}\right)^{-\frac{\theta}{\eta}} + \left(1 - n_{it+s}\right) n_{it+s-1}\left(P^*_{it+s-1}\right)^{-\frac{\theta}{\eta}} + \cdots$$

$$+ \prod_{j=1}^{s}\left(1 - n_{it+j}\right) n_{it}\left(P^*_{it}\right)^{-\frac{\theta}{\eta}} + \prod_{j=1}^{s}\left(1 - n_{it+j}\right)\left(1 - n_{it}\right)\left(X_{it-1}\right)^{-\frac{\theta}{\eta}}$$

back

Steady-State Output and Productivity

$$y^{\frac{1}{\eta}} = \eta \frac{1-\beta(1-n)\pi^{\frac{\theta}{\eta}}}{1-\beta(1-n)\pi^{\theta-1}} \left(\frac{n}{1-(1-n)\pi^{\theta-1}} \right)^{\frac{1+\theta\left(\frac{1}{\eta}-1\right)}{\theta-1}}$$

$$x^{\theta} = \left(\frac{1-(1-n)\pi^{\frac{\theta}{\eta}}}{n} \right)^{\eta} \left(\frac{1-(1-n)\pi^{\theta-1}}{n} \right)^{-\frac{\theta}{\theta-1}}$$

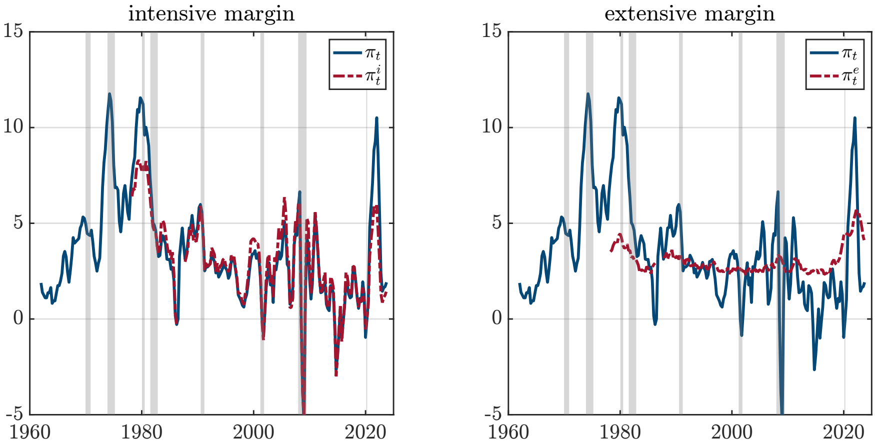
back

Role of Extensive Margin

- Decompose $\pi_t = \Delta_t n_t$ into two components
  - Δ_t : average price change conditional on adjustment
  - n_t : fraction of price changes

- Isolate role of each using Klenow and Kryvtsov (2008) decomposition
  - intensive margin: $\pi_t^i = \Delta_t \bar{n}$
    - $\bar{n}$: mean fraction of price changes
  - extensive margin: $\pi_t^e = \bar{\Delta} n_t$
    - $\bar{\Delta}$: mean average price change

Role of Extensive Margin: Data



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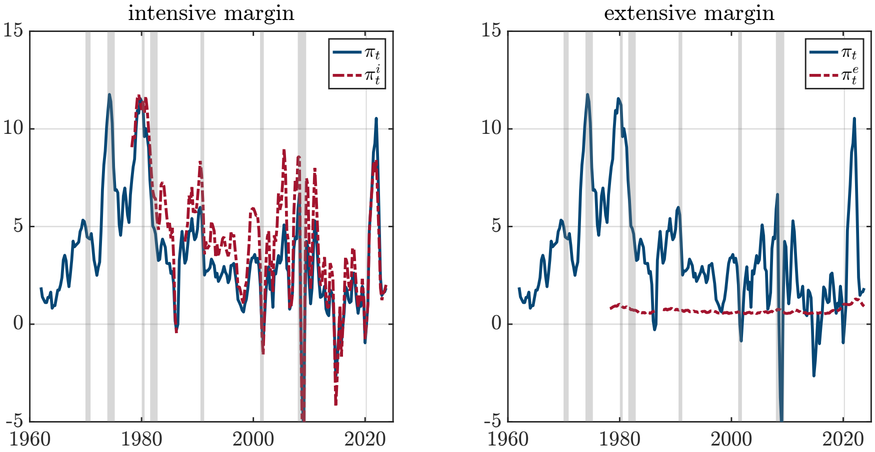
Montag and Villar (2024)

- Argue that extensive margin plays no role post Covid
- Same decomposition but set $\bar{n}$ and $\bar{\Delta}$ equal to January 2020 values
  - due to seasonality, unusually large n and low Δ
- Illustrate fixing $\bar{n}$ and $\bar{\Delta}$ at January 2020 values

Role of Extensive Margin using January 2020



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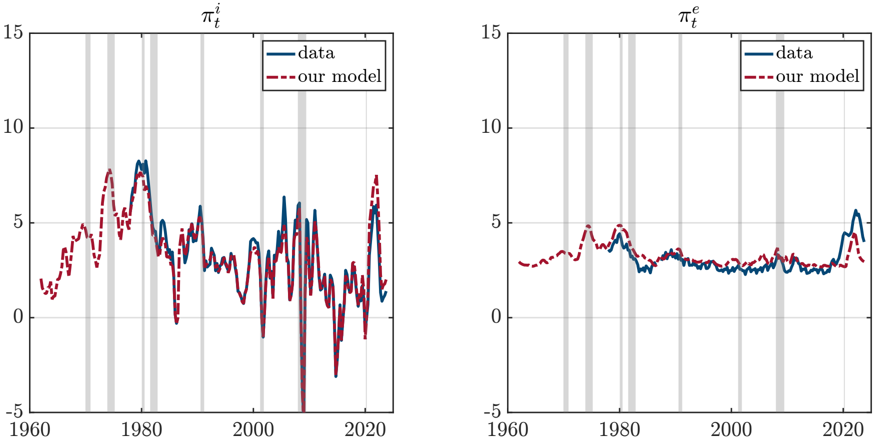
Role of Extensive Margin: Our Model



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