

INFLATION PERSISTENCE AND A NEW PHILLIPS CURVE

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October 2024

MOTIVATION

- ▶ NK-model is dominant paradigm for studying business cycles and stabilization
- ▶ Standard model features simple **time-dependent** price-adjustment frictions
- ▶ Built around the New Keynesian Phillips Curve (NKPC):

$$\pi_t = \alpha \sum_{j=0}^{\infty} \beta^j \mathbb{E} [m c_{t+j}]$$

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$$\pi_t = \alpha \sum_{j=0}^{\infty} \beta^j \mathbb{E} [m c_{t+j}]$$

- ▶ However empirical literature estimating NKPC finds inflation persistence (Gali and Gertler, 1999; Fuhrer, 2010)

$$\pi_t = \hat{\alpha} \sum_{j=0}^{\infty} \beta^j \mathbb{E} [m c_{t+j}] + \hat{\gamma} \pi_{t-1}, \quad \hat{\gamma} > 0 \text{ significant and relevant}$$

WHAT WE DO

- ▶ **State-dependent** "menu-cost" model (Golosov and Lucas, 2007; Midrigan, 2011)
- ▶ Study shocks to the **growth rate** of nominal demand
- ▶ Quarterly **autocorrelation** $\rho_D = 0.5$
- ▶ Solve non-linearly for an **MIT-shock** on the growth rate of nominal demand
- ▶ IRF as **numerical derivative** to simulate (Boppart, Krusell, and Mitman, 2018)
- ▶ Run **Phillips-Curve regressions**

MAIN FINDINGS

Menu Cost + Growth Rate Shocks:

- ▶ **Inflation inertia:** hump-shaped response in a purely forward looking model
- ▶ Break the **perfect comovement** between inflation and MC
- ▶ Replicate **inflation persistence** in the NKPC

KEY IDEA

- ▶ In **Calvo model**:
 - ▶ Only **intensive margin** movements in prices
 - ▶ Purely forward looking
- ▶ In **state-dependent** model:
 - ▶ Now adds **extensive margin** choice of when to adjust prices
 - ▶ Distribution of prices matters for which firms adjust
 - ▶ **History dependence**:
past variables \Rightarrow distribution \Rightarrow **ext. margin** \Rightarrow inflation
 - ▶ Amplified by **autocorrelated growth rate** shocks

QUANTITATIVE PRICE SETTING MODEL

High level modeling choices

- ▶ Follow Midrigan (ECMA 2011)
- ▶ Weekly frequency
- ▶ Firm productivity with idiosyncratic shocks
- ▶ Stochastic (exponential) adjustment costs
- ▶ No mass points – continuous price distribution

SIMPLE HOUSEHOLD DEMAND

- Composite consumption:

$$C_t = \left[\int_0^1 c_t(i)^{\frac{\epsilon-1}{\epsilon}} di \right]^{\frac{\epsilon}{\epsilon-1}}.$$

- Households $\max C_t$ s.t.

$$D_t = \int_0^1 p_t(i)c_t(i)di$$

- Demand for each good i :

$$c_t(i) = \left(\frac{p_t(i)}{P_t} \right)^{-\epsilon} \frac{D_t}{P_t},$$

- Price index:

$$P_t = \left[\int_0^1 p_t(i)^{1-\epsilon} di \right]^{\frac{1}{1-\epsilon}}$$

- Intratemporal consumption-leisure optimality:

$$MC_t = \frac{W_t}{P_t} = \frac{u_h(C_t, H_t)}{u_c(C_t, H_t)} = \left(\frac{D_t}{P_t} \right)^{\varphi+\sigma}$$

PRICE SETTING MODEL WITH IDIOSYNCRATIC PRODUCTIVITY

- ▶ Firms have linear technology in labor $y_t = z_t l_t$
- ▶ Real profits at time t with productivity z_t and price p_t :

$$\left(\frac{p_t}{P_t} - MC \left(\frac{D_t}{P_t} \right) \frac{1}{z_t} \right) \left(\frac{p_t}{P_t} \right)^{-\epsilon} \frac{D_t}{P_t}.$$

- ▶ Rewriting using firm-specific markup μ_t :

$$\underbrace{(\mu_t - 1) \mu_t^{-\epsilon} z_t^{\epsilon-1}}_{\text{idiosyncratic}} \times \underbrace{\left(MC \left(\frac{D_t}{P_t} \right) \right)^{1-\epsilon} \frac{D_t}{P_t}}_{\text{aggregate}}.$$

PRICE SETTING MODEL

INFINITE HORIZON

$$V_t^{\text{noadj}}(\mu, z) = (\mu - 1)\mu^{-\epsilon}z^{\epsilon-1} \times (MC_t)^{1-\epsilon} \frac{D_t}{P_t}$$

$$+ \beta \mathbb{E} V_{t+1}(\mu', z')$$

$$\text{s.t. } z' = \eta' z$$

$$\mu' = \eta' \frac{P_t}{P_{t+1}} \frac{MC_t}{MC_{t+1}} \mu$$

PRICE SETTING MODEL INFINITE HORIZON

$$V_t^{\text{noadj}}(\mu, z) = (\mu - 1)\mu^{-\epsilon}z^{\epsilon-1} \times (MC_t)^{1-\epsilon} \frac{D_t}{P_t}$$

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$$\mu' = \eta' \frac{P_t}{P_{t+1}} \frac{MC_t}{MC_{t+1}} \mu$$

$$V_t^{\text{adj}}(\mu, z|\xi) = \max_{\mu^*} (\mu^* - 1)(\mu^*)^{-\epsilon} z^{\epsilon-1} \times (MC_t)^{1-\epsilon} \frac{D_t}{P_t} - z^{\epsilon-1} \xi$$

$$+ \beta \mathbb{E} V_{t+1}(\mu', z')$$

s.t. $z' = \eta' z$

$$\mu' = \eta' \frac{P_t}{P_{t+1}} \frac{MC_t}{MC_{t+1}} \mu^*$$

PRICE SETTING MODEL INFINITE HORIZON

$$V_t^{\textcolor{red}{noadj}}(\mu, z) = (\mu - 1)\mu^{-\epsilon}z^{\epsilon-1} \times (MC_t)^{1-\epsilon} \frac{D_t}{P_t}$$

$$+ \beta \mathbb{E} V_{t+1}(\mu', z')$$

s.t. $z' = \eta' z$

$$\mu' = \eta' \frac{P_t}{P_{t+1}} \frac{MC_t}{MC_{t+1}} \mu$$

$$V_t^{\textcolor{red}{adj}}(\mu, z|\xi) = \max_{\mu^*} (\mu^* - 1)(\mu^*)^{-\epsilon} z^{\epsilon-1} \times (MC_t)^{1-\epsilon} \frac{D_t}{P_t} - z^{\epsilon-1} \xi$$

$$+ \beta \mathbb{E} V_{t+1}(\mu', z')$$

s.t. $z' = \eta' z$

$$\mu' = \eta' \frac{P_t}{P_{t+1}} \frac{MC_t}{MC_{t+1}} \mu^*$$

$$V_t(\mu, z) = \max\{V_t^{\textcolor{red}{noadj}}(\mu, z), V_t^{\textcolor{red}{adj}}(\mu, z|\xi)\}$$

SHOCKS AND MENU COSTS

- Productivity follows a geometric random walk:

$$z_{t+1} = \eta z_t$$

$$\log(\eta_{t+1}) = p u_t + (1 - p) \frac{u_t}{10}, \quad u_t \sim \mathcal{N}(-(\epsilon - 1) \sigma_\eta^2 / 2, \sigma_\eta^2)$$

- Menu costs: $\xi_t \sim Exp(\kappa)$:

$$\mathbb{P}(\xi_t \leq x) = 1 - e^{-\kappa x}$$

- Calibrate p, σ_η, κ to match key steady state targets from Midrigan (2011)

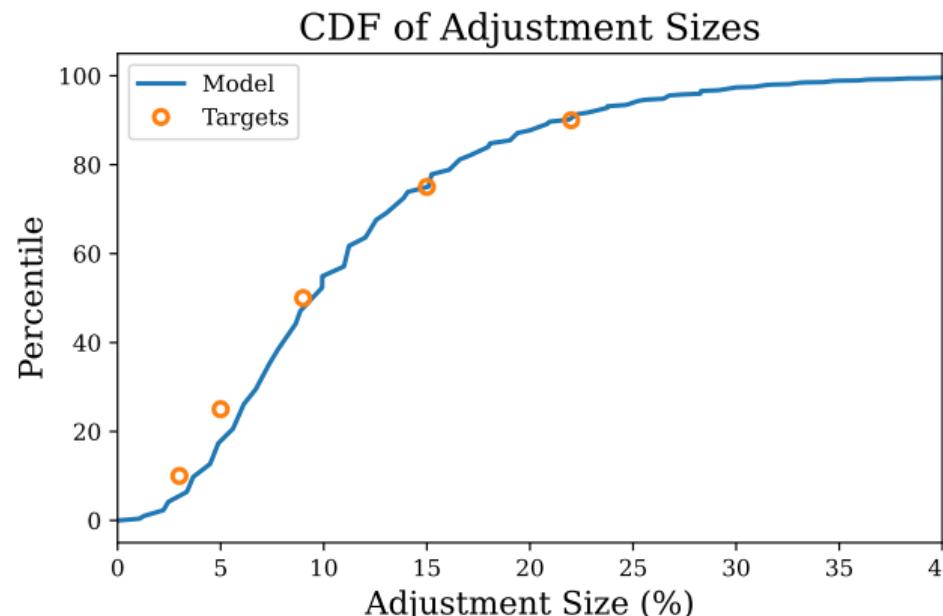
CALIBRATION

Parameter	Value	Description	Source
β	$0.96^{1/52}$	Discount factor	Midrigan (2011)
σ	1	CRRA	Midrigan (2011)
ψ	1	Frisch elasticity	Midrigan (2011)
ϵ	3	Elasticity of subst.	Midrigan (2011)
p_t	0.022	Mixture weight	Internal
σ_η	0.127	Volatility	Internal
κ	1.35	Menu cost	Internal

CALIBRATION TARGETS

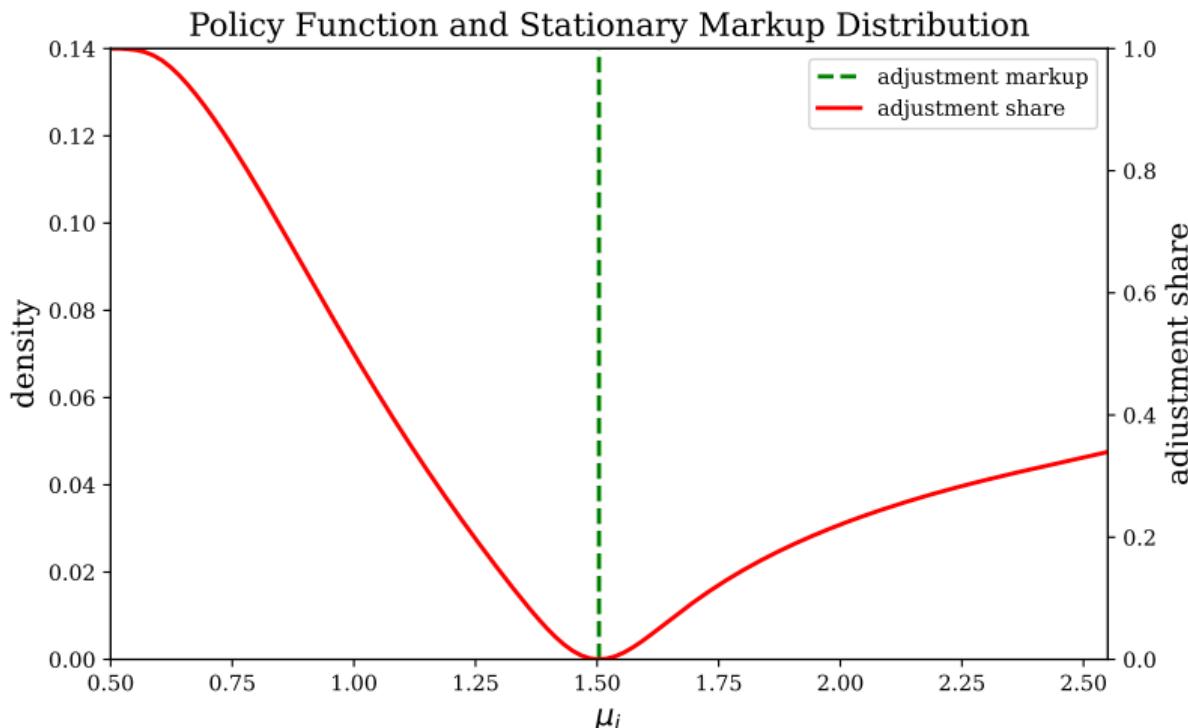
Targets from **Midrigan, 2011**:

- ▶ Frequency of (regular) weekly price changes: **2.9%**
- ▶ Average size of price changes: **11.1%**
- ▶ Size distribution of (regular) price changes:



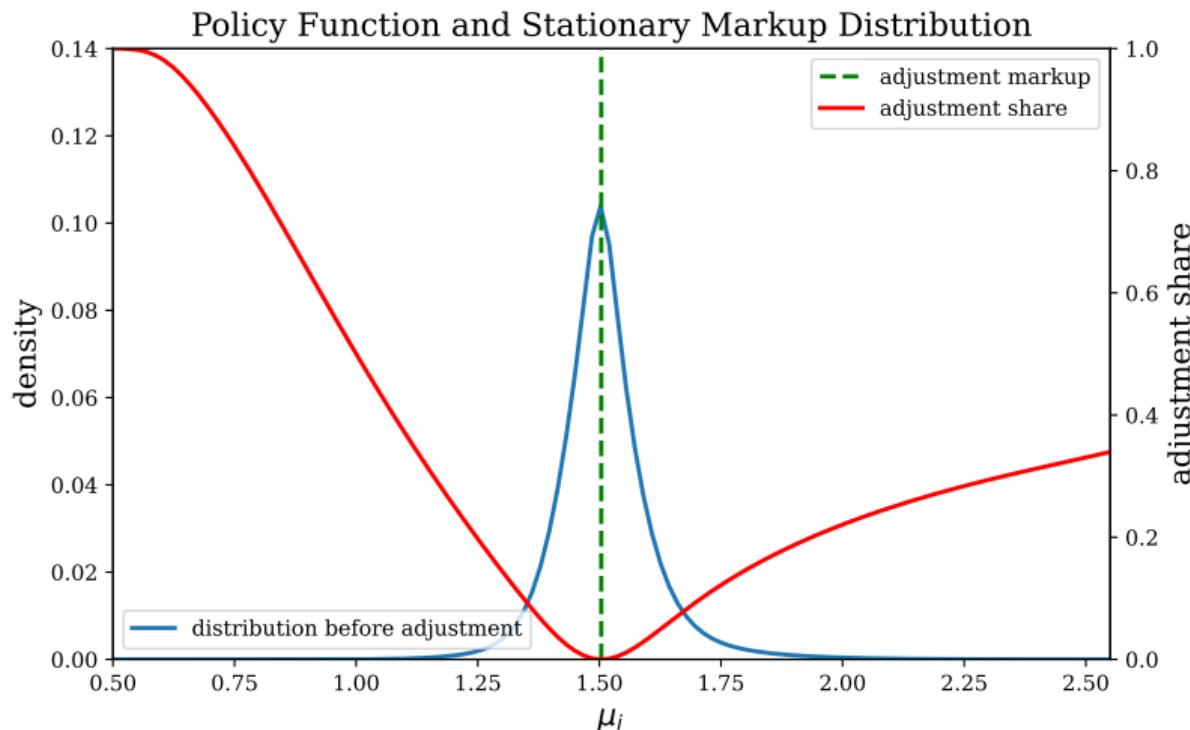
STEADY STATE

- ▶ Steady state with 2% annual inflation



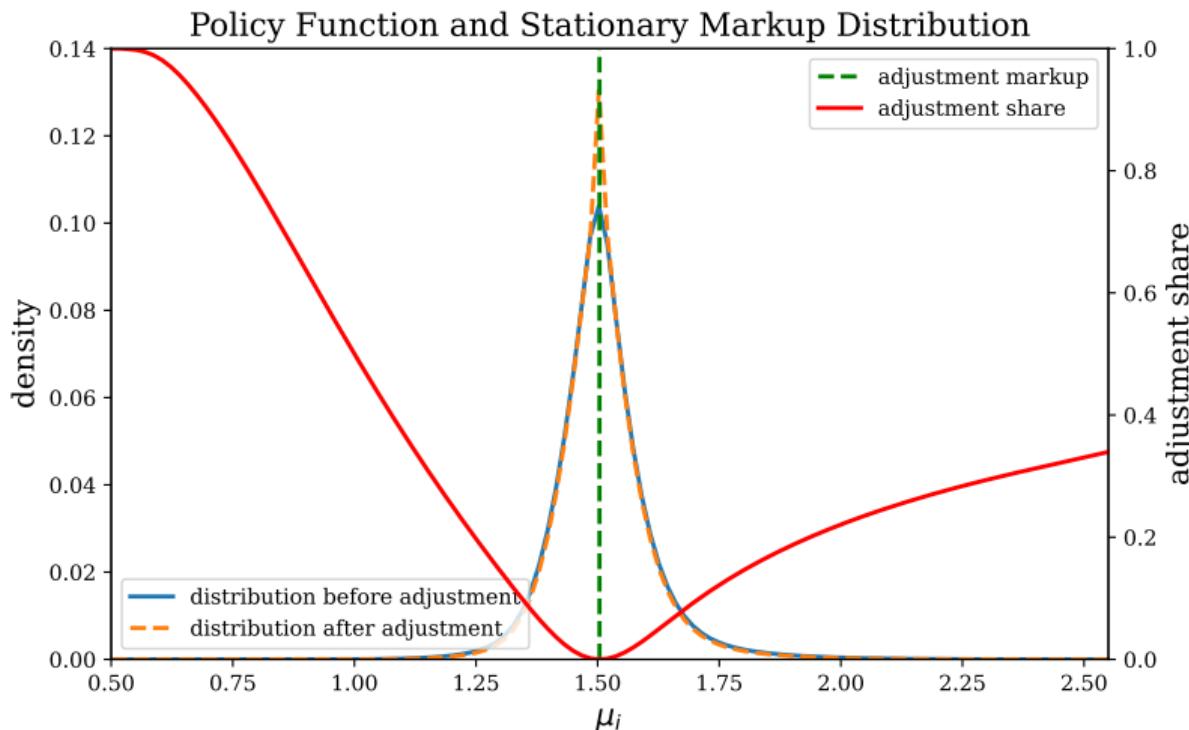
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INTENSIVE AND EXTENSIVE MARGIN MODEL AND DATA

Validation Experiments:

- ▶ Compare steady-state properties of **intensive** and **extensive** margin to empirical results in Alvarez, Beraja, Gonzalez-Rozada and Neumeyer (2019):
“From hyperinflation to stable prices: Argentina’s evidence on menu cost models”
- ▶ Experiment: increase steady-state growth rate of nominal demand
⇒ increased steady-state inflation rate (all other parameters unchanged)

INFLATION ACCOUNTING IDENTITY

- Inflation accounting into intensive and extensive margins:

$$\pi = \lambda^+ \Delta^+ - \lambda^- \Delta^-$$

- Where:

- λ^+ : Frequency of price increases
- λ^- : Frequency of price decreases
- Δ^+ : Average size of price increases
- Δ^- : Average size of price decreases

INFLATION ACCOUNTING IDENTITY

- ▶ Inflation accounting into intensive and extensive margins:

$$\pi = \lambda^+ \Delta^+ - \lambda^- \Delta^-$$

- ▶ Where:

- ▶ λ^+ : Frequency of price increases
- ▶ λ^- : Frequency of price decreases
- ▶ Δ^+ : Average size of price increases
- ▶ Δ^- : Average size of price decreases

- ▶ Changes in inflation decomposed into extensive and intensive margin:

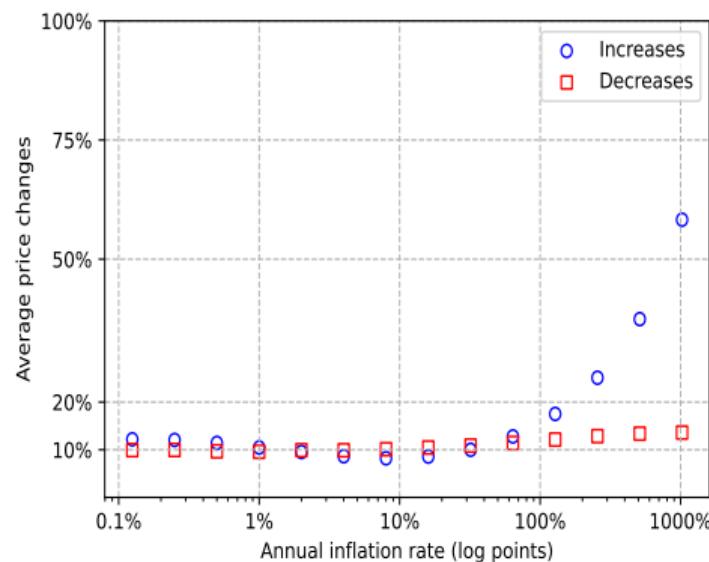
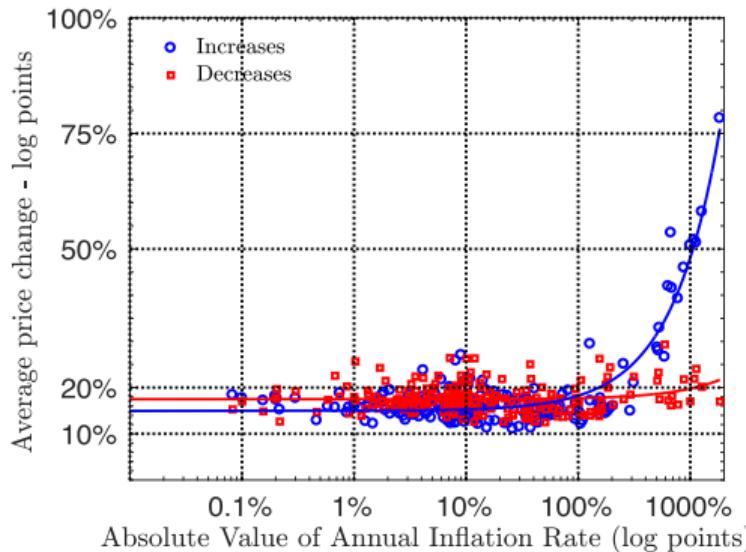
$$\frac{\partial \pi_t}{\partial \pi_t} = \underbrace{\frac{\partial \lambda^+}{\partial \pi_t} \Delta^+ - \frac{\partial \lambda^-}{\partial \pi_t} \Delta^-}_{\text{Extensive Margin}} + \underbrace{\lambda^+ \frac{\partial \Delta^+}{\partial \pi_t} - \lambda^- \frac{\partial \Delta^-}{\partial \pi_t}}_{\text{Intensive Margin}}$$

INTENSIVE MARGIN

$$\frac{\partial \Delta^+}{\partial \pi}, \quad \frac{\partial \Delta^-}{\partial \pi}$$

DATA

MODEL

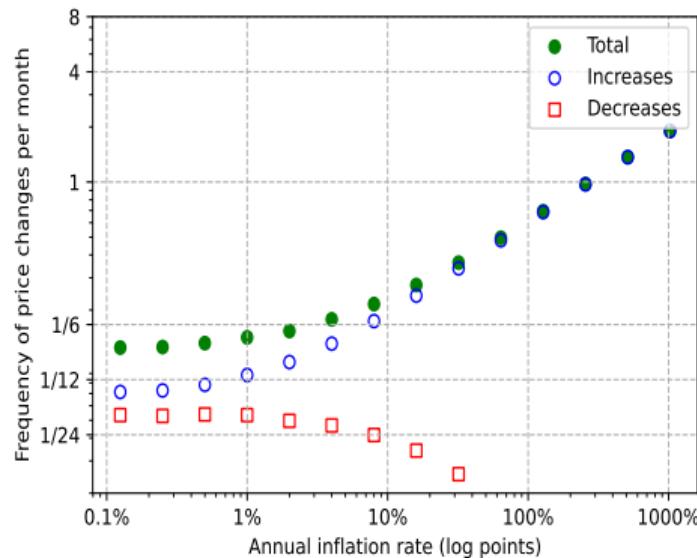
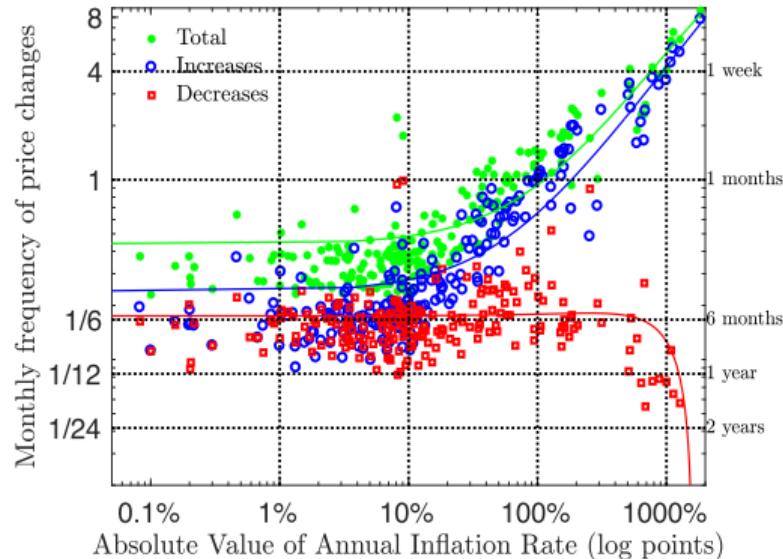


EXTENSIVE MARGIN

$$\frac{\partial \lambda^+}{\partial \pi}, \quad \frac{\partial \lambda^-}{\partial \pi}, \quad \frac{\partial \lambda^+}{\partial \pi} + \frac{\partial \lambda^-}{\partial \pi}$$

DATA

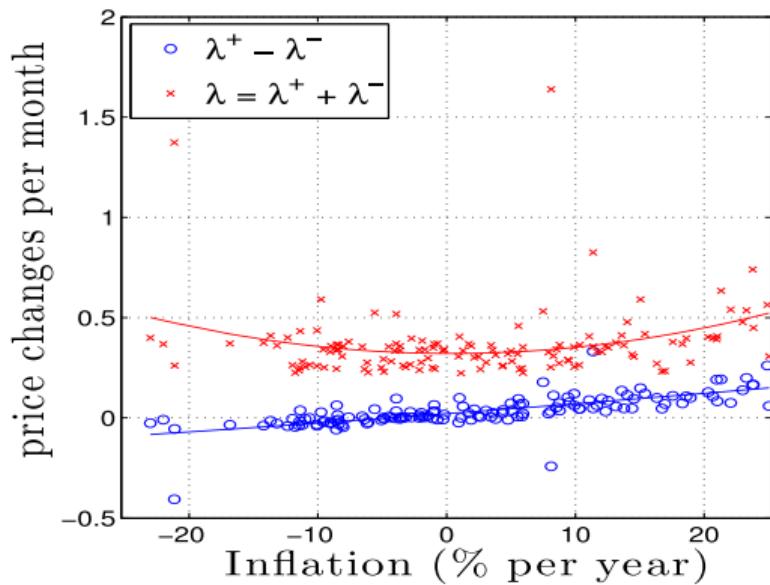
MODEL



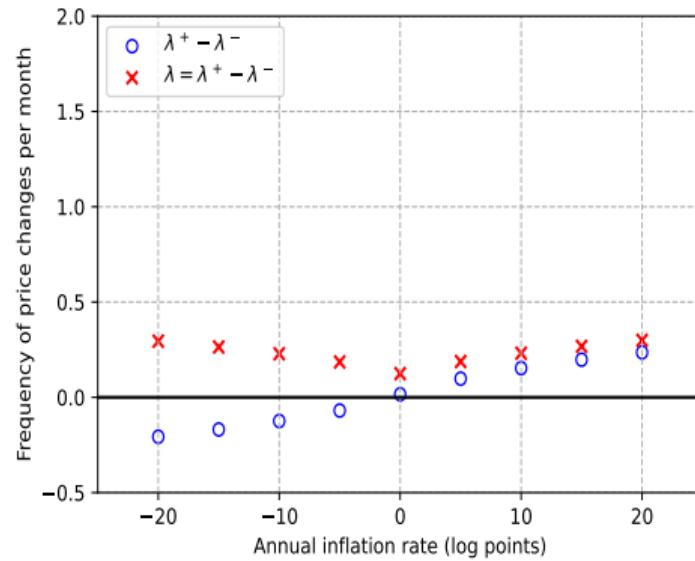
SELECTION EFFECT

$$\frac{\partial(\lambda^+ - \lambda^-)}{\partial\pi}, \quad \frac{\partial(\lambda^+ + \lambda^-)}{\partial\pi}$$

DATA



MODEL



EXPERIMENTS

- ▶ Study response of model to shocks to nominal demand growth ΔD_t
- ▶ Consider quarterly autocorrelation $\rho_D = 0.5$ (as in the data)
- ▶ Linearize model with small MIT-shocks in sequence space (Boppart, Krusell & Mitman 2018, Auclert et al 2021)
- ▶ Implement quarterly Phillips curve regressions

RESULTS: DEMAND SHOCK $\rho_D = 0.5$

New Keynesian Calvo Specifications:

$$\pi_t = \alpha \sum \mathbb{E}[\beta^k m c_{t+k}] + \gamma \pi_{t-1} + \epsilon_t$$

	$\sum \beta^k m c_{t+k}$	π_{t-1}
Calvo PC	1.0963 (0.014)	
+ Lagged Inflation	0.8623 (0.011)	0.4588 (0.0078)

Standard errors in parentheses.

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New Keynesian Calvo Specifications:

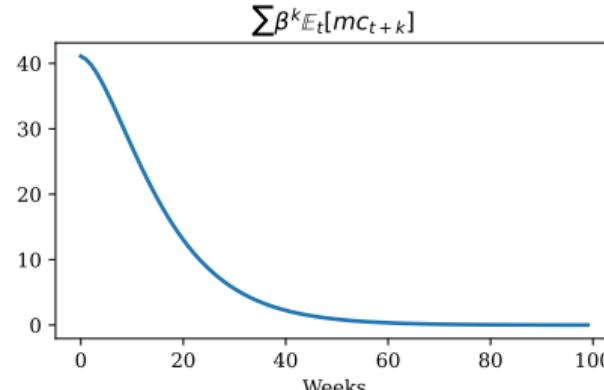
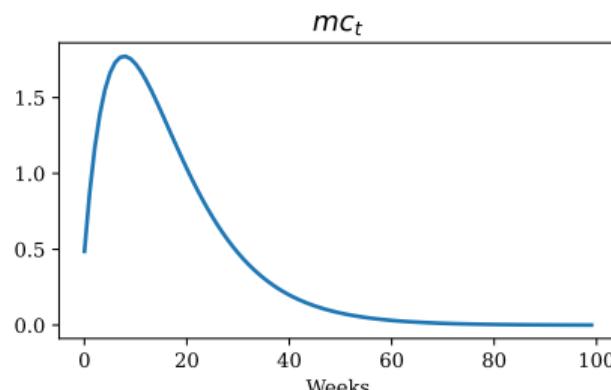
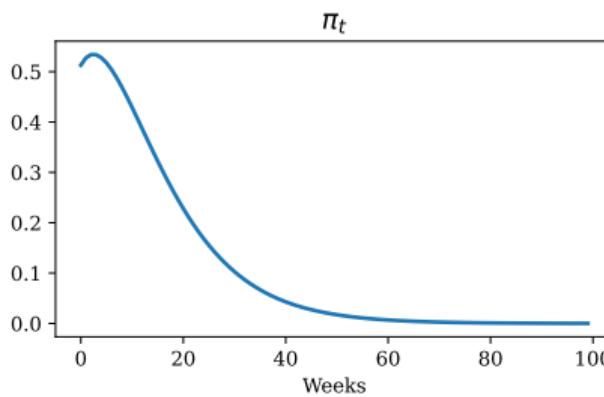
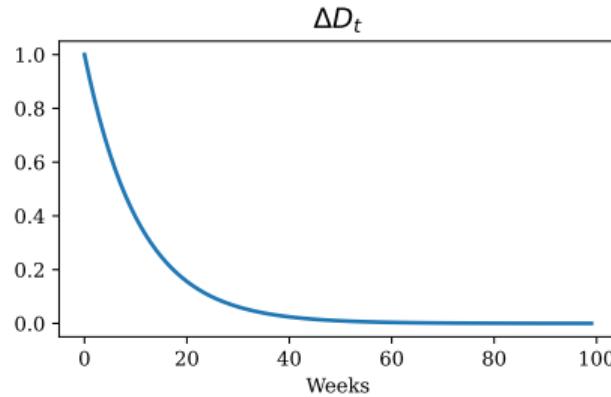
$$\pi_t = \alpha \sum \mathbb{E}[\beta^k m c_{t+k}] + \gamma \pi_{t-1} + \delta \Delta D_{t-1} + \epsilon_t$$

	$\sum \beta^k m c_{t+k}$	π_{t-1}	ΔD_{t-1}
Calvo + Lagged Inflation	0.8623 (0.0011)	0.4588 (0.0078)	
Full Specification	0.5325 (0.0069)	0.0071 (0.0063)	7.4127 (0.0764)

Standard errors in parentheses.

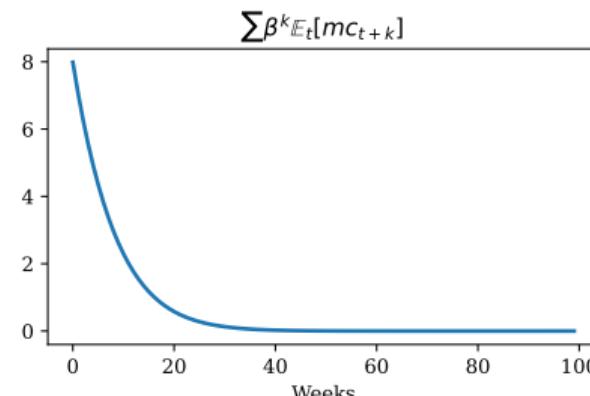
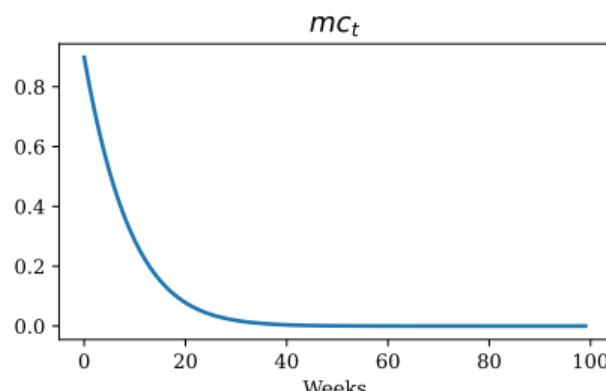
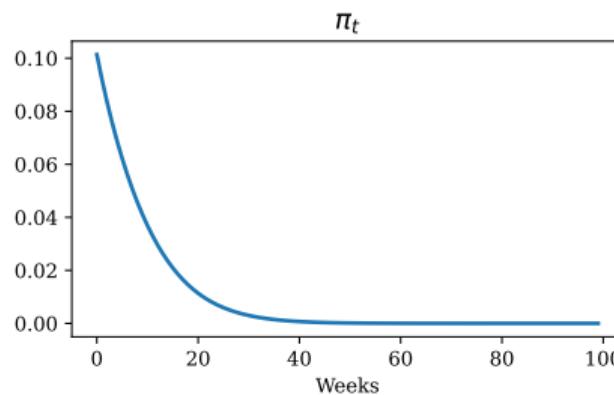
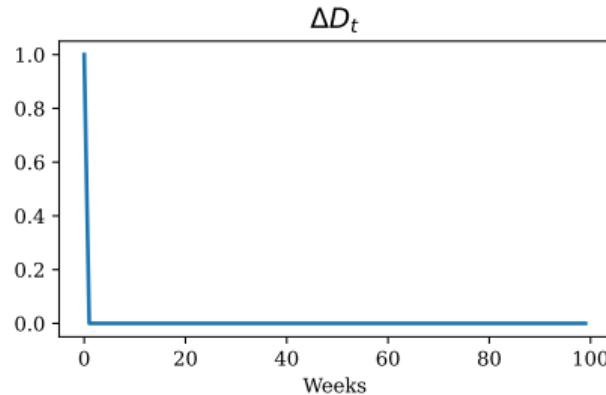
UNDERSTANDING THE RESULTS

$\rho_D = 0.5$; NO FULL FRONTLOADING

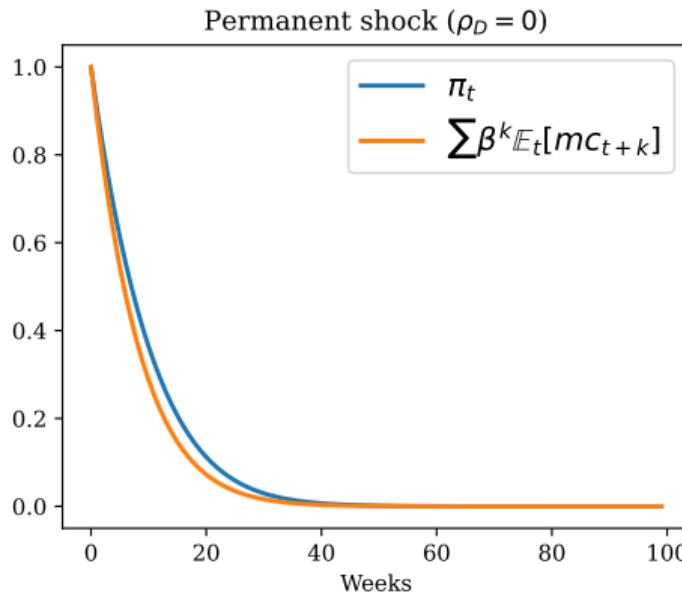
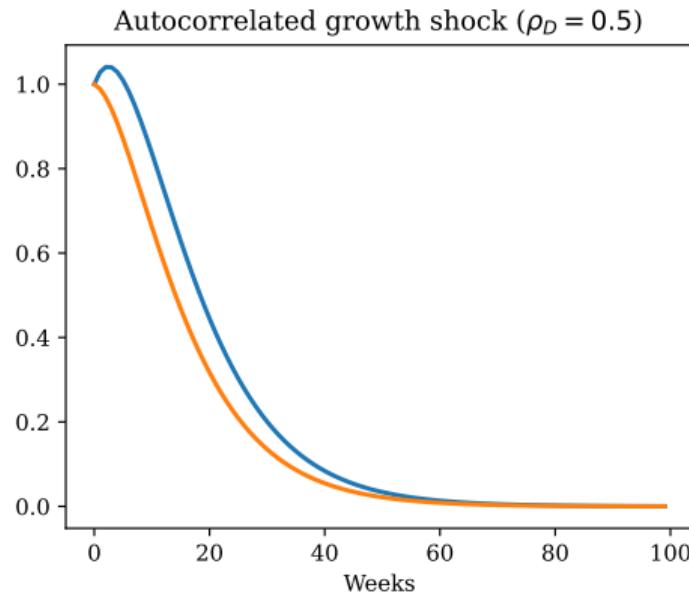


UNDERSTANDING THE RESULTS

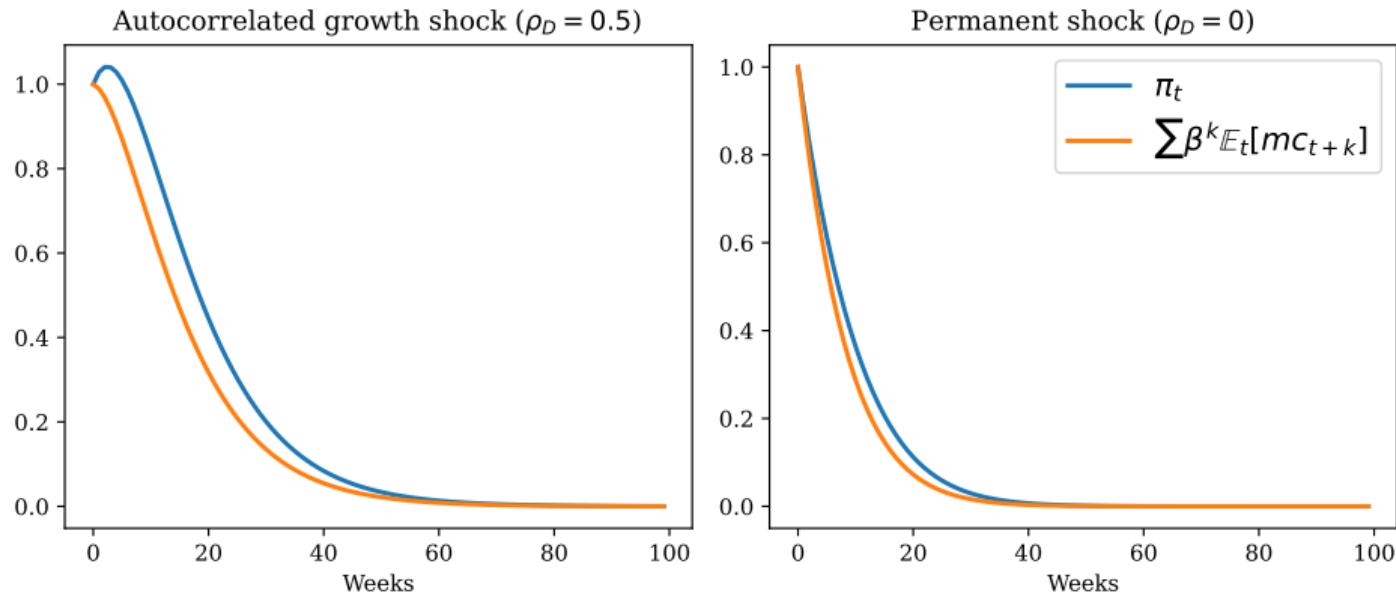
$\rho_D = 0$; FULL FRONTLOADING



NORMALIZED IRFS



NORMALIZED IRFs



$$\pi_t = 0.011 \sum_{k=0}^{\infty} \beta^k m c_{t+k} + 0.25 \pi_{t-1},$$

$$\pi_t = 0.012 \sum_{k=0}^{\infty} \beta^k m c_{t+k} + 0.13 \pi_{t-1}$$

CONCLUSION

- ▶ In the **data**: estimated NKPC exhibits inflation persistence
- ▶ In **Calvo model**: one-to-one relationship between inflation and marginal costs
- ▶ We showed that **menu-cost model**:
 - ▶ can replicate empirical findings on NKPC
 - ▶ **breaks one-to-one relationship between inflation and marginal costs**
 - ▶ nominal demand (and other past variables) matter for inflation dynamics
- ▶ Next steps: add realistic household block, study non-linearities ...

COMPARISON TO AUCLERT ET AL 2024

With AR(1) shocks ($\rho = \{0.3, 0.6, 0.8\}$) to **real marginal costs**, inflation and (expected discounted) output gaps coincide

