Optimal monetary policy under menu costs

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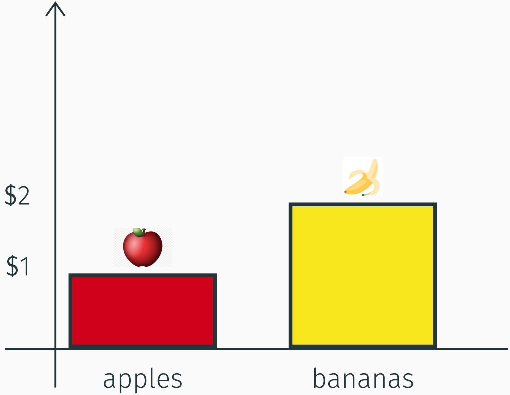
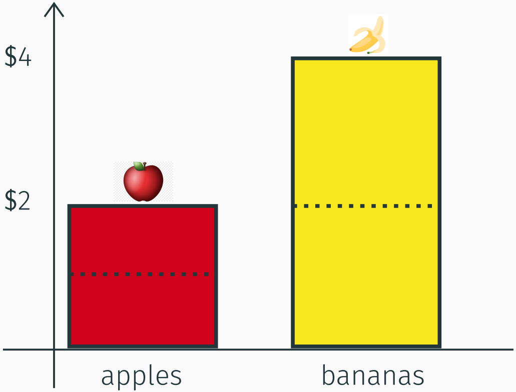


What should central banks do?

Background: **Why does monetary policy matter?**

Benchmark: monetary policy *doesn't* matter

- Money supply doubles
  $\Longrightarrow$ all prices double
  $\Longrightarrow$ nothing *real* affected by monetary policy



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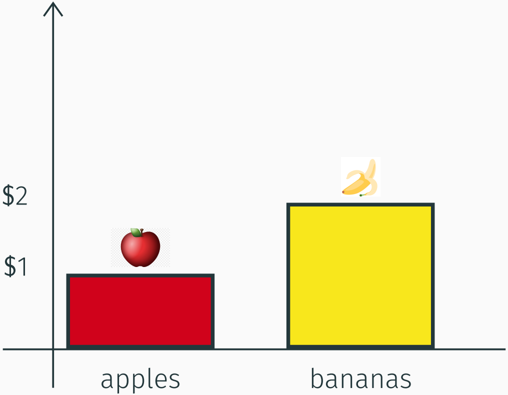

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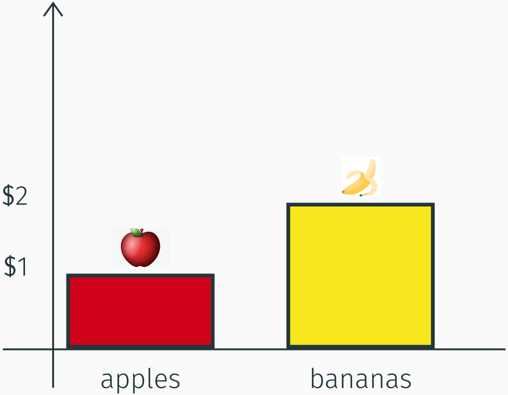
Background: **Why does monetary policy matter?**

Prices are *sticky*



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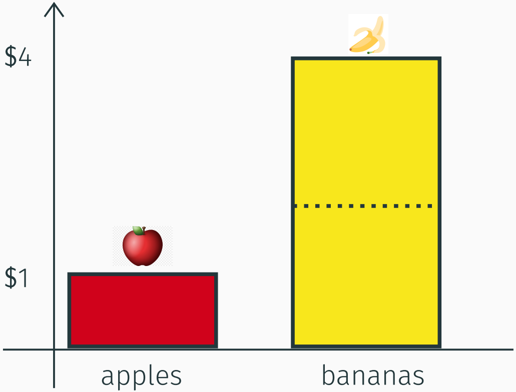
  $\Longrightarrow$ some prices are stuck
  $\Longrightarrow$ **distorted** relative prices



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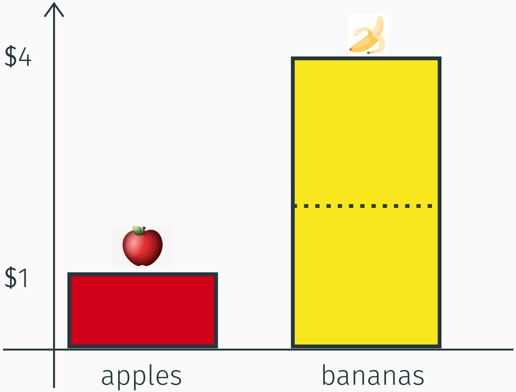
  $\implies$ **distorted** relative prices
- Large empirical literature ▸ more



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$\Longrightarrow$ **Optimal policy:** Inflation targeting [Woodford 2003; Rubbo 2023]

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$\Longrightarrow$ **Optimal policy:** Inflation targeting *[Woodford 2003; Rubbo 2023]*

Criticism:

1. Theoretical critique: Not microfounded
2. Empirical critique: State-dependent pricing is a better fit

   [Nakamura et al 2018; Cavallo and Rigobon 2016; Alvarez et al 2018; Cavallo et al 2023]

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1. **Stylized analytical model**
2. **Quantitative model**

Related literature

Contribution: first to fully characterize optimal policy under menu costs

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1. Optimal monetary policy with sectors / relative prices

- Calvo *[Rubbo 2023, Woodford 2003, Aoki 2001, Benigno 2004]*
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2. Menu costs, *assume* inflation targeting, solve for optimal inflation target

[Wolman 2011, Nakov-Thomas 2014, Blanco 2021]

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$\Longrightarrow$ first-order approximation, without direct costs

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4. Non-normative menu cost literature

- Theoretical *[Golosov-Lucas 2007; Caballero-Engel 2007; Nakamura-Steinsson 2009; Alvarez-Lippi-Paciello 2011; Midrigan 2011; Gertler-Leahy 2008; Auclert et al 2023]*
- Empirical *[Nakamura et al 2018; Cavallo-Rigobon 2016; Alvarez et al 2018; Gautier-Le Bihan 2022]*

Roadmap

1. Baseline model & optimal policy
2. Extensions
3. Quantitative model
4. Comparison to Calvo model
5. Conclusion and bigger picture

Model setup + household's problem

General setup:

- Off-the shelf sectoral model with S sectors
- Each sector is a continuum of firms, bundled with CES technology
- Static model (& no linear approximation)

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$$\max_{C,N,M} \ln(C) - N + \ln\left(\frac{M}{P}\right)$$
$$\text{s.t. } PC + M = WN + D + M_{-1} - T$$
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Optimality conditions:

$$c_i = \frac{1}{S}\frac{PC}{p_i}$$

$$PC = M$$

$$W = M$$

Intermediate firms: price setting with menu costs

▸ more production structure

Technology: In given sector i, continuum of firms $j \in [0,1]$ with technology

$$y_i(j) = A_i \cdot n_i(j)$$

Demand: $y_i(j) = y_i \left(\frac{p_i(j)}{p_i}\right)^{-\eta}$

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Menu cost: adjusting price requires ψ extra units of labor

- χ_i: indicator for price change vs. not

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$\Longrightarrow$ **Direct cost of menu costs:** excess disutility of labor

$$N = \sum_i n_i + \psi \sum_i \chi_i$$

- Other specifications do not affect result more

Menu costs induce an inaction region

▸ Full equilibrium characterization

Objective function of sector i firm: $\left(p_i y_i - \frac{W}{A_i} y_i (1-\tau)\right) - W\psi\chi_i$

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If not adjusting: inherited price p_i^{old}

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Inaction region: don't adjust iff $p_i^* = \frac{W}{A_i}$ close to p_i^{old}

Optimal policy after a productivity shock

▸ Formal planner's problem

- Start at steady state: all sectors have $A_i^{ss} = 1 \;\; \forall i, \quad$ so $p_i^{ss} = W^{ss} \equiv 1$

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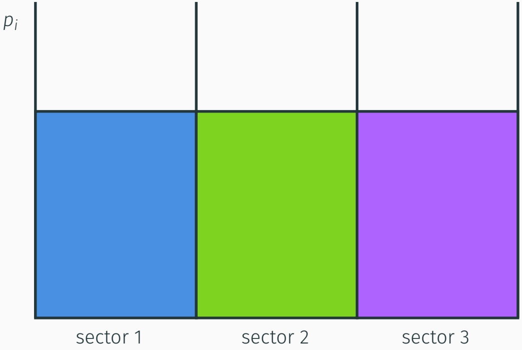
2. If shock is small, $A_1 < \bar{A}$, then optimal policy is to ensure no sector adjusts:

$$p_i = p_i^{ss} \quad \forall i$$

Large-enough shocks

▸ math ▸ more math

Recall: $p_i^* = MC_i = \frac{W}{A_i}$



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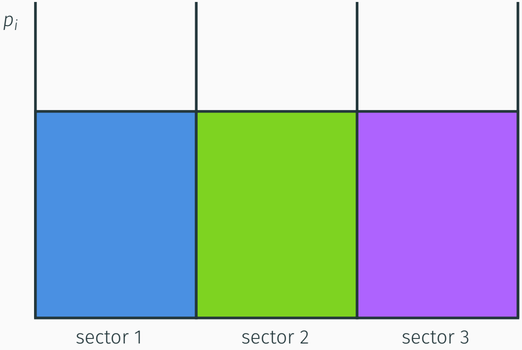

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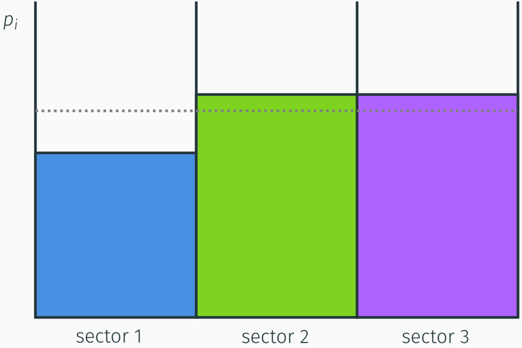

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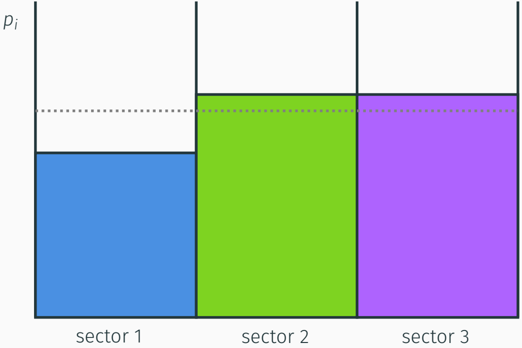

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$\mathbb{W}^f - S\psi$

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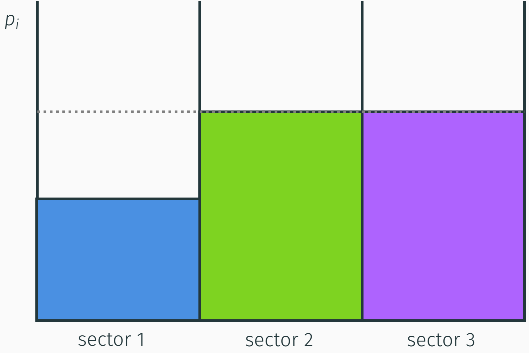

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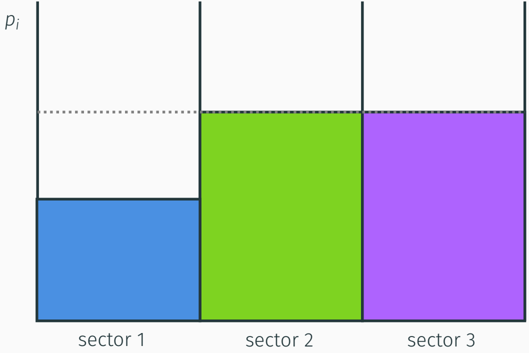

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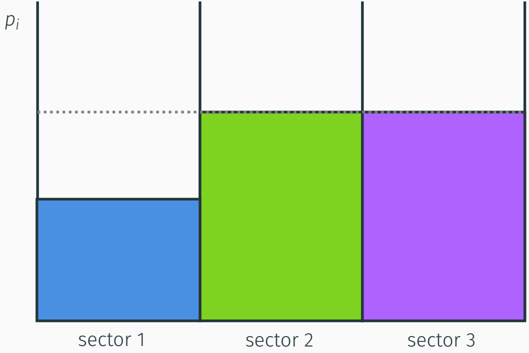

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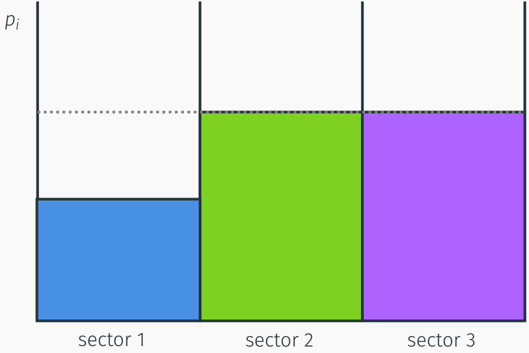

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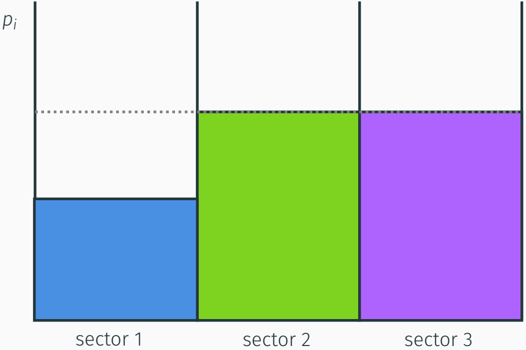

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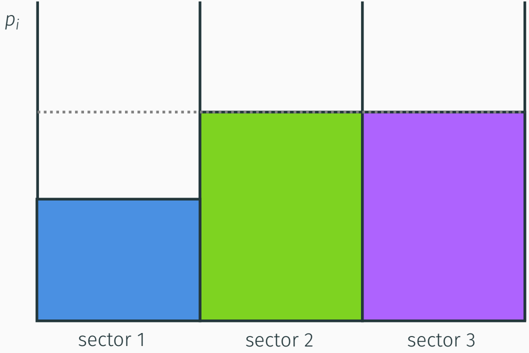

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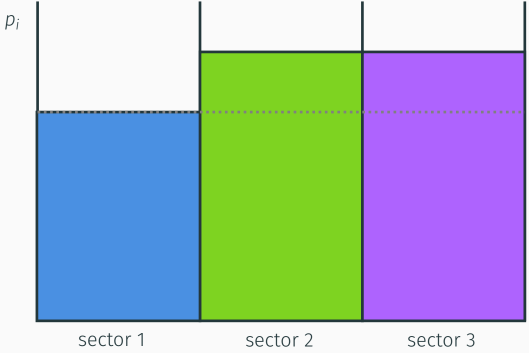

Only sectors k adjusts

$\mathbb{W}^f - (S-1)\psi$

Small shocks: state dependence of optimal policy

▸ math ▸ more math

	Sectors k adjust	Sectors k not adjust
Sector 1 adjusts		
Sector 1 not adjust		

Small shocks: state dependence of optimal policy

▸ math ▸ more math

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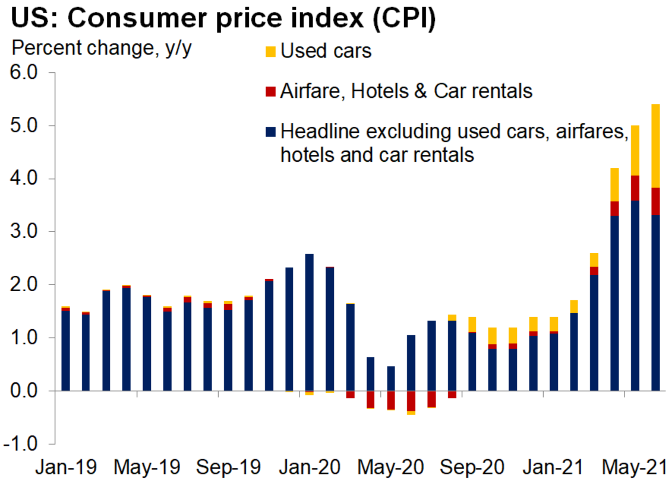
Lemma 2: $\exists\, \bar{A}$ such that

$$\mathbb{W}_{\text{only 1 adjusts}} > \mathbb{W}_{\text{none adjust}}$$

iff $A_1 > \bar{A}$. Furthermore, $\bar{A}$ is increasing in ψ.

Interpretation: “looking through” shocks

Example 1: used cars (2021)



Source : Oxford Economics/BLS

Interpretation: “looking through” shocks

Example 2: energy shock (2022)

EUROPEAN CENTRAL BANK
EUROSYSTEM

Looking through higher energy prices? Monetary policy and the green transition

Isabel Schnabel, Member of the ECB’s Executive Board

The welfare loss of inflation targeting

"Inflation targeting": $P = P^{ss}$ (while having correct relative prices)

Proposition 2: Suppose $A_1 > \bar{A}$. Then:

1. Inflation targeting requires all sectors adjust their prices
2. Welfare loss from inflation targeting $\propto$ size of menu costs

$$\mathbb{W}^* - \mathbb{W}^{IT} = (S - 1)\psi$$

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1. **Physical adjustment costs.** Baseline interpretation.

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What are menu costs?

1. **Physical adjustment costs.** Baseline interpretation.
2. **Information costs.** Fixed costs of information acquisition / processing.
   - Results unchanged
3. **Behavioral costs.** Consumer *distaste* for price changes.
   - Results unchanged

How large are menu costs?

Summary: at least 0.5% of firm revenues, plausibly much more

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1. Calibrated models.

(1) Measure *frequency of price adjustment*

(2) Build structural model

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- 0.5% of firm revenues

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2. Direct measurement. For *physical* adjustment costs,

Levy et al (1997, QJE): 5 grocery chains

- 0.7% revenue

Dutta et al (1999, JMCB): drugstore chain

- 0.6% revenue

Zbaracki et al (2003, Restat): mfg

- 1.2% revenue

Generalized model: stabilize nominal MC of unshocked firms

Generalized model:

1. Any (HOD1) aggregator: $C = F(c_1, ..., c_S)$
2. Potentially DRS production technology: $y_i(j) = A_i n_i(j)^{1/\alpha}$ with $1/\alpha \in (0, 1]$
3. Any preferences quasilinear in labor: $U\left(C, \frac{M}{P}\right) - N$

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Proposition 1 extended: optimal policy stabilizes **nominal marginal costs of unshocked firms**

$\implies Y \uparrow, P \downarrow$

"Macro functional forms"

More general example:

1. $C = \prod c_i^{1/S}$

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Proposition 1 extended: optimal policy stabilizes **nominal marginal costs of unshocked firms**

$\implies$ stabilize a weighted average of wages and prices, $W^{\lambda} P^{1-\lambda}$

Production networks: stabilize a weighted average of P and W

Baseline model:

- Production technology:

$$y_i = A_i n_i$$

Roundabout production network:

- Production technology:

$$y_i = A_i n_i^{\beta} I_i^{1-\beta}$$
$$I_i = \prod_{k=1}^{S} I_i(k)^{1/S}$$

Production networks: stabilize a weighted average of P and W

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- Marginal cost:

$$MC_i = \frac{W}{A_i}$$

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- Optimal policy: stabilize nominal MC of unshocked sectors: stabilize W

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Perfectly uniform shocks

multiple shocks

Proposition 3: Consider any shock not affecting relative prices, e.g. a perfectly uniform shock: $A_1 = ... = A_S \equiv A$.

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Proof idea:

- Relative prices don't need to change

Perfectly uniform shocks

▸ multiple shocks

Proposition 3: Consider any shock not affecting relative prices, e.g. a perfectly uniform shock: $A_1 = ... = A_S \equiv A$. Then optimal policy is to stabilize *inflation*.

Proof idea:

- Relative prices don't need to change
- Stable prices thus guarantee:
    1. Correct relative prices
    2. Zero direct costs

Additional extensions

1. Under sticky wages due to menu costs, optimal policy still stabilizes W;

   ▸ more

2. Optimal policy is not about selection effects: a CalvoPlus model

   ▸ more

3. Heterogeneity across sectors: a monetary “least-cost avoider” principal

   ▸ more

1. Baseline model & optimal policy

2. Extensions

3. **Quantitative model**

4. Comparison to Calvo model

5. Conclusion and bigger picture

Appendix

Quantitative model: setup and solution method

Dynamic model with **idiosyncratic** + sectoral shocks

Household

$$\max_{\{C_t, N_t, B_t, M_t\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\gamma}}{1-\gamma} - \omega \frac{N_t^{1+\varphi}}{1+\varphi} + \ln\left(\frac{M_t}{P_t}\right) \right]$$

$$\text{s.t.} \quad P_t C_t + B_t + M_t \leq R_t B_{t-1} + W_t N_t + M_{t-1} + D_t - T_t$$

Intermediate firms

$$\max_{p_{it}(j), \chi_{it}(j)} \sum_{t=0}^{\infty} \mathbb{E} \left[\frac{1}{R^t P_t} \{ p_{it}(j)\, y_{it}(j) - W_t n_{it}(j)\,(1-\tau) - \chi_{it}(j) \psi W_t \} \right]$$

$$\text{s.t.} \quad y_{it}(j) = A_{it}\, a_{it}(j)\, n_{it}(j)^{\alpha} \quad \text{and} \quad R^t = \prod_{\tau=0}^{t} R_\tau$$

where idiosyncratic productivity follows an AR(1)

$$\log\left(a_{it}(j)\right) = \rho_{\text{idio}} \log\left(a_{it-1}(j)\right) + \varepsilon_t^{\text{idio}}$$

Calibration

Two sets of parameters to calibrate:

(1) standard or drawn from literature and

	Parameter (quarterly frequency)	Value	Target
β	Discount factor	0.99	standard
ω	Disutility of labor	1	standard
φ	Inverse Frisch elasticity	0	Golosov-Lucas 2007
γ	Inverse EIS	2	standard
S	Number of sectors	6	Nakamura-Steinsson 2010
η	Elasticity of subst. between sectors	5	standard value
α	Returns to scale	0.6	standard value

Calibration

Two sets of parameters to calibrate:

(1) standard or drawn from literature and (2) calibrated by SMM targeting

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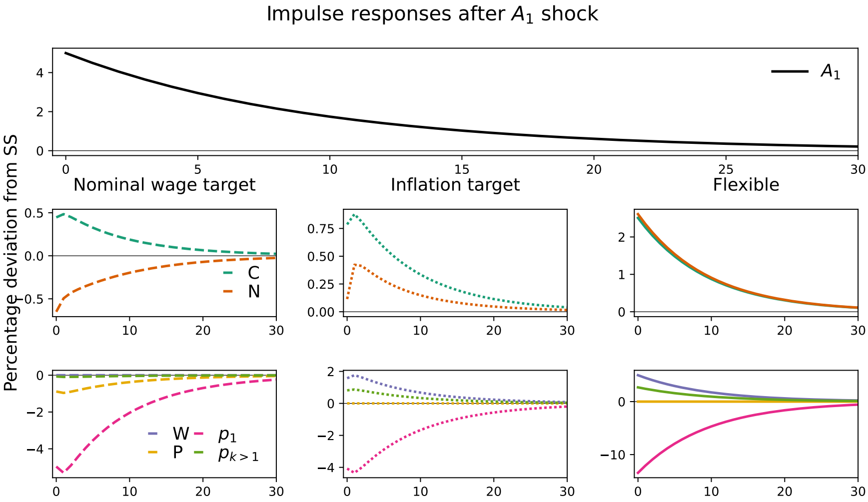
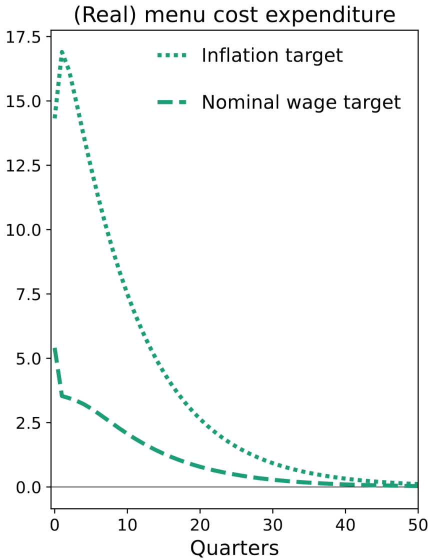
α	Returns to scale	0.6	standard value
σ_{idio}	Std. of idio. shocks	0.13	menu cost expenditure / revenue $\sim$ 1%
ρ_{idio}	Persistence of idio. shocks	0.86	and
ψ	Menu cost	0.016	share of price changers $\sim$ 26.1%

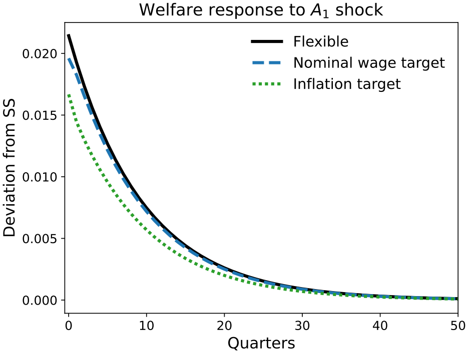
Exercise: perfect foresight sectoral shock



Policy comparison: menu cost expenditure



Policy comparison: welfare



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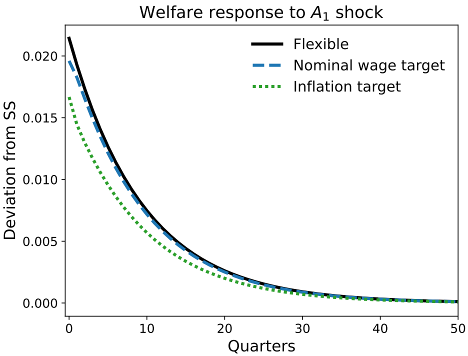
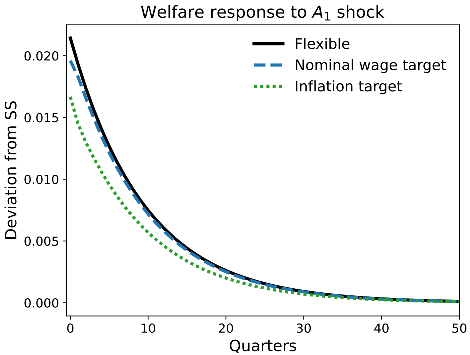


1. Consider welfare under W targeting

Policy comparison: welfare



1. Consider welfare under W targeting
2. How much extra C is needed to match welfare under flexible prices?

$$\sum_t \beta^t U\left((1+\lambda)C_t,\ N_t\right) = \sum_t \beta^t U\left(C_t^{\text{flex}},\ N_t^{\text{flex}}\right)$$

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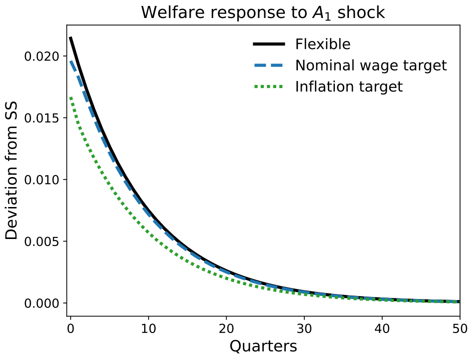

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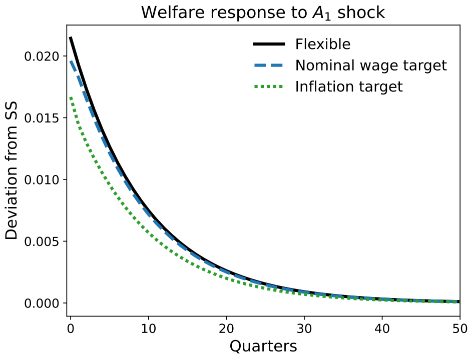

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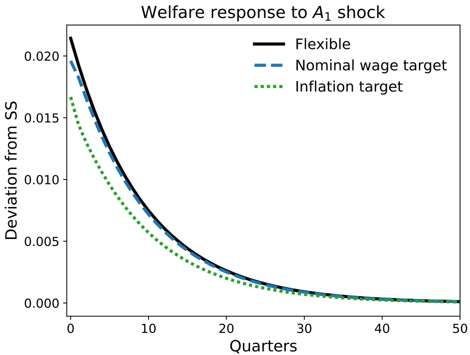

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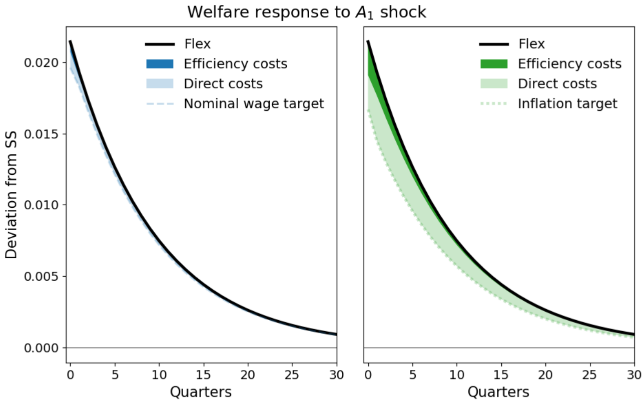
$\Longrightarrow$ **welfare loss of sticky prices −80.6%**

Decomposing welfare



1. **Direct costs:** $\psi\chi_t$, disutility of labor from menu costs
2. **Efficiency costs:** welfare loss from incorrect relative prices

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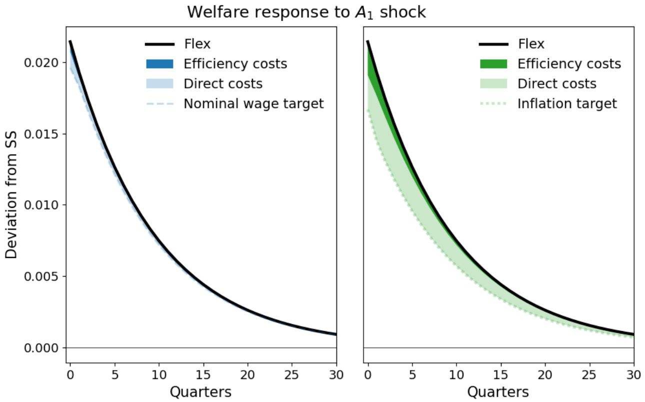

1. **Direct costs:** $\psi\chi_t$, disutility of labor from menu costs

2. **Efficiency costs:** welfare loss from incorrect relative prices

- Direct costs: $\tilde{\lambda}^W = 0.0007\%$ and $\tilde{\lambda}^P = 0.0060\%$
- Recall total welfare losses: $\lambda^W = 0.0040\%$ and $\lambda^P = 0.0200\%$
- **Interpretation:** welfare improvement comes from both channels

Numerically-optimal policy in simple class of rules

Consider monetary policy rules stabilizing:

$$W^{\xi} P^{1-\xi}$$

$$\xi \in [0, 1]$$

Recall λ: "how much extra C needed to match welfare response of flex-price economy?"

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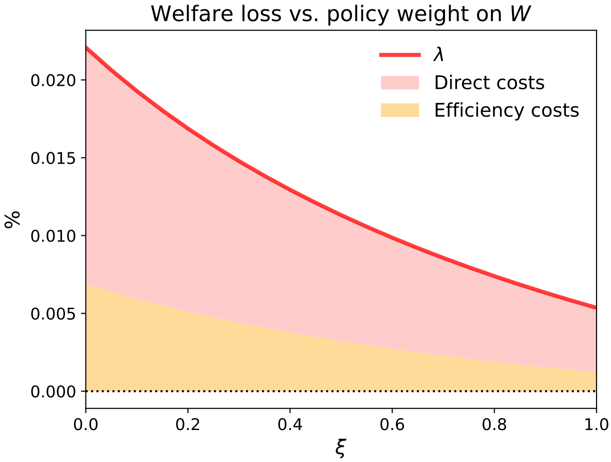
Numerically-optimal policy: Stabilize W alone



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2. Extensions
3. Quantitative model
4. **Comparison to Calvo model**
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Appendix

Why not inflation targeting?

▸ more

- **Multisector Calvo optimal policy: inflation targeting,** $P = P^{ss}$. Why?

  [Woodford; Rubbo; Aoki; cf Guerrieri-Lorenzoni-Straub-Werning]

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Convex costs $\Longrightarrow$ *smooth* price changes across sectors

Comparison with Calvo model

▸ more

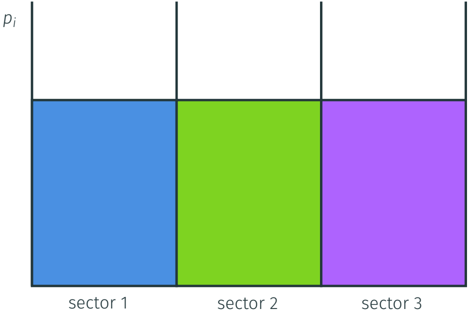
Calvo: Likewise, *welfare cost of price dispersion is convex*:

$$\Delta \equiv \sum_{i=1}^{S} \int_0^1 \left[\frac{p_i(j)}{p_i}\right]^{-\eta} dj$$

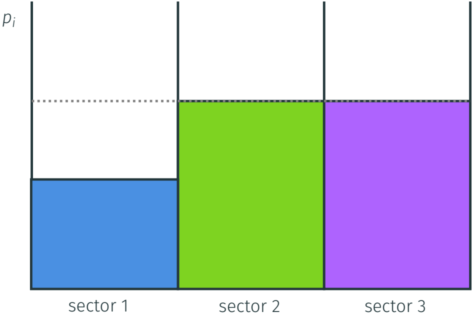
where $\eta > 1$ is the within-sector elasticity of substitution

Calvo diagram: shocking sector-1 productivity

▸ math



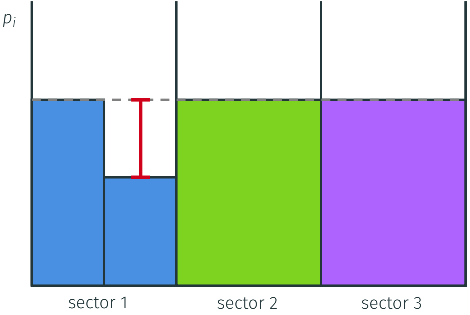
Steady state



Flexible prices, after shock

Calvo diagram: shocking sector-1 productivity

▸ math



Nominal wage targeting under Calvo

Lots of price dispersion: *only* one sector

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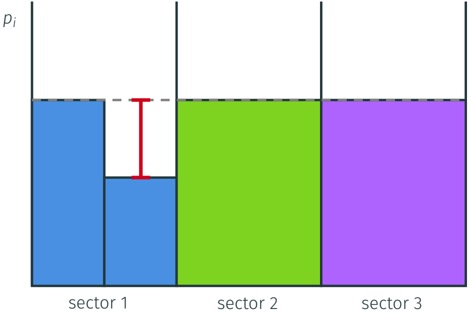

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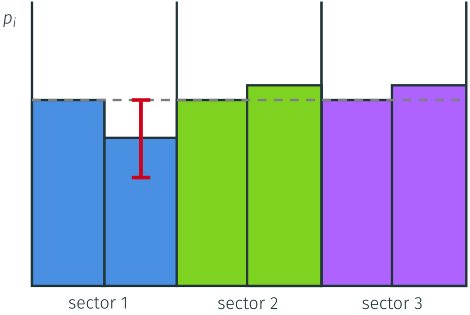

Inflation targeting under Calvo

Lots of price dispersion: *only* one sector

Little price dispersion: *all* sectors

“Robustly” optimal monetary policy?

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Fundamental principle of optimal monetary policy: Optimal policy is *entirely* a function of the nominal friction added to an underlying frictionless RBC model

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- RBC + cash = Friedman rule
- RBC + Calvo = inflation targeting
- RBC + menu costs = countercyclical inflation

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- RBC + ...

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4. Sticky prices [**new**]: **Caratelli and Halperin (2024)**

Summary

In baseline menu cost model, **inflation should be countercyclical** after sectoral shocks

Rationale:

- Inflation targeting **forces firms to adjust unnecessarily**, which is costly with menu costs
- Nominal wage targeting does not

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In baseline menu cost model, **inflation should be countercyclical** after sectoral shocks

Rationale:

- Inflation targeting **forces firms to adjust unnecessarily**, which is costly with menu costs
- Nominal wage targeting does not

Future work:

- Convexity of menu costs
- Better direct measurement of menu costs
- "Unified theory of optimal monetary policy"?

Thank you!

Equilibrium characterization

Back

Sectoral packagers:

$$y_i = \left[\int_0^1 y_i(j)^{\frac{\eta-1}{\eta}} dj\right]^{\frac{\eta}{\eta-1}}$$

$$y_i(j) = y_i \left[\frac{p_i(j)}{p_i}\right]^{-\eta}$$

$$p_i = \left[\int_0^1 p_i(j)^{1-\eta} dj\right]^{\frac{1}{1-\eta}}$$

Intermediate producers:

$$y_i(j) = A_i n_i(j)$$

$$p_i(j)^{\text{opt}} = \frac{\eta}{\eta-1}(1-\tau)\frac{W}{A_i}$$

$$\chi_i = \mathbb{I}\left\{\frac{1}{\eta} > y_i \left[\frac{p_i^{\text{old}}}{p_i}\right]^{-\eta} \left(p_i^{\text{old}} - \frac{W}{A_i}\frac{\eta-1}{\eta}\right)\right\}$$

Household:

$$M = PC$$

$$M = W$$

$$C = \prod C_i^{1/S}$$

$$P = S \prod p_i^{1/S}$$

Government:

$$1 - \tau = \frac{\eta - 1}{\eta}$$

$$-T + (M - M_{-1}) = \tau W \sum n_i$$

Market clearing:

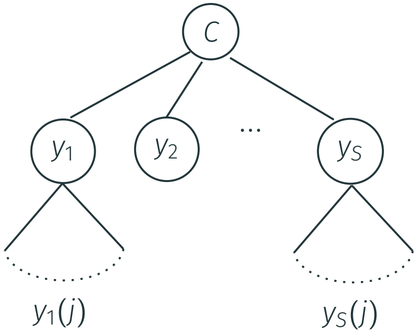
$$N = \sum n_i + \psi \sum \chi_i$$

Production structure

back

Final goods demand:

$$C = \prod y_i^{1/S}$$
$$P = S \prod p_i^{1/S}$$
$$y_i = \frac{1}{S}\frac{PC}{p_i}$$



Sectoral packagers (competitive):

$$y_i = \left[\int_0^1 y_i(j)^{\frac{\eta-1}{\eta}} dj\right]^{\frac{\eta}{\eta-1}}$$
$$y_i(j) = y_i \left[\frac{p_i(j)}{p_i}\right]^{-\eta}$$
$$p_i = \left[\int_0^1 p_i(j)^{1-\eta} dj\right]^{\frac{1}{1-\eta}}$$

Equilibrium in four possible regimes

back

	Sectors k adjust	**Sectors k not adjust**
Sector 1 adjusts	$\cdot$	$\cdot$
Sector 1 not adjust	$\cdot$	$\cdot$

Equilibrium in four possible regimes

back

	Sectors k adjust	Sectors k not adjust
Sector 1 adjusts	.	.
Sector 1 not adjust	.	.

Flexible price benchmark ($\psi = 0$):

Equilibrium in four possible regimes

back

	Sectors k adjust	Sectors k not adjust
Sector 1 adjusts	.	.
Sector 1 not adjust	.	.

Flexible price benchmark ($\psi = 0$):

- $p_1 = \frac{W}{A_1}$ and $p_k = W$
- Key object: relative price

$$\left(\frac{p_1}{p_k}\right)_{\text{flex}} = \frac{1}{A_1}$$

Equilibrium in four possible regimes

back

	Sectors k **adjust**	**Sectors** k **not adjust**
Sector 1 **adjusts**	.	.
Sector 1 **not adjust**	.	.

Flexible price benchmark ($\psi = 0$**):**

- $p_1 = \frac{W}{A_1}$ and $p_k = W$
- Key object: relative price

$$\left(\frac{p_1}{p_k}\right)_{\text{flex}} = \frac{1}{A_1}$$

- $C_{\text{flex}} = A_1^{1/S}/S$; and $N_{\text{flex}} = 1$
- Flex-price welfare:
  $\mathbb{W}_{\text{flex}} = \ln\left(C_{\text{flex}}\right) - N_{\text{flex}}$

Equilibrium in four possible regimes

back

	Sectors k adjust	**Sectors k not adjust**
Sector 1 adjusts	·	·
Sector 1 not adjust	·	·

Flexible price benchmark ($\psi = 0$):

- $p_1 = \frac{W}{A_1}$ and $p_k = W$
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- Flex-price welfare:
  $\mathbb{W}_{\text{flex}} = \ln\left(C_{\text{flex}}\right) - N_{\text{flex}}$

All adjust:

Equilibrium in four possible regimes

back

	Sectors k adjust	Sectors k not adjust
Sector 1 adjusts	.	.
Sector 1 not adjust	.	.

Flexible price benchmark ($\psi = 0$):

- $p_1 = \frac{W}{A_1}$ and $p_k = W$
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$\mathbb{W}_{\text{flex}} = \ln\left(C_{\text{flex}}\right) - N_{\text{flex}}$

All adjust:

- $p_1 = \frac{W}{A_1}$ and $p_k = W$
- Key object: relative price

$$\left(\frac{p_1}{p_k}\right)_{\text{all adjust}} = \frac{1}{A_1}$$

Equilibrium in four possible regimes

back

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Sector 1 not adjust	.	.

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  $\mathbb{W}_{\text{flex}} = \ln\left(C_{\text{flex}}\right) - N_{\text{flex}}$

All adjust:

- $p_1 = \frac{W}{A_1}$ and $p_k = W$
- Key object: relative price

$$\left(\frac{p_1}{p_k}\right)_{\text{all adjust}} = \frac{1}{A_1} = \left(\frac{p_1}{p_k}\right)_{\text{flex}}$$

Equilibrium in four possible regimes

back

	Sectors k adjust	Sectors k not adjust
Sector 1 adjusts	.	.
Sector 1 not adjust	.	.

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- $p_1 = \frac{W}{A_1}$ and $p_k = W$
- Key object: relative price

$$\left(\frac{p_1}{p_k}\right)_{\text{all adjust}} = \frac{1}{A_1} = \left(\frac{p_1}{p_k}\right)_{\text{flex}}$$

- $C = C_{\text{flex}}$; and $N = N_{\text{flex}} + S\psi$

Equilibrium in four possible regimes

back

	Sectors k adjust	Sectors k not adjust
Sector 1 adjusts	.	.
Sector 1 not adjust	.	.

Flexible price benchmark ($\psi = 0$):

- $p_1 = \frac{W}{A_1}$ and $p_k = W$
- Key object: relative price

$$\left(\frac{p_1}{p_k}\right)_{\text{flex}} = \frac{1}{A_1}$$

- $C_{\text{flex}} = A_1^{1/S}/S$; and $N_{\text{flex}} = 1$
- Flex-price welfare: $\mathbb{W}_{\text{flex}} = \ln\left(C_{\text{flex}}\right) - N_{\text{flex}}$

All adjust:

- $p_1 = \frac{W}{A_1}$ and $p_k = W$
- Key object: relative price

$$\left(\frac{p_1}{p_k}\right)_{\text{all adjust}} = \frac{1}{A_1} = \left(\frac{p_1}{p_k}\right)_{\text{flex}}$$

- $C = C_{\text{flex}}$; and $N = N_{\text{flex}} + S\psi$
- Welfare: $\mathbb{W}_{\text{all adjust}} = \mathbb{W}_{\text{flex}} - S\psi$

Equilibrium in four possible regimes

back

	Sectors k adjust	Sectors k not adjust
Sector 1 adjusts	$\mathbb{W}_{\text{flex}} - S\psi$	.
Sector 1 not adjust	.	.

Flexible price benchmark ($\psi = 0$):

- $p_1 = \frac{W}{A_1}$ and $p_k = W$
- Key object: relative price

$$\left(\frac{p_1}{p_k}\right)_{\text{flex}} = \frac{1}{A_1}$$

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$$\left(\frac{p_1}{p_k}\right)_{\text{all adjust}} = \frac{1}{A_1} = \left(\frac{p_1}{p_k}\right)_{\text{flex}}$$

- $C = C_{\text{flex}}$; and $N = N_{\text{flex}} + S\psi$
- Welfare: $\mathbb{W}_{\text{all adjust}} = \mathbb{W}_{\text{flex}} - S\psi$

Equilibrium in four possible regimes (2)

	Sectors k adjust	**Sectors k not adjust**
Sector 1 adjusts	$\mathbb{W}_{\text{flex}} - S\psi$	$\cdot$
Sector 1 not adjust	$\cdot$	$\cdot$

Flexible price benchmark ($\psi = 0$):

- $p_1 = \frac{W}{A_1}$ and $p_k = W$
- Key object: relative price

$$\left(\frac{p_1}{p_k}\right)_{\text{flex}} = \frac{1}{A_1}$$

- $C_{\text{flex}} = A_1^{1/S}/S$; and $N_{\text{flex}} = 1$
- Flex-price welfare:
  $\mathbb{W}_{\text{flex}} = \ln\left(C_{\text{flex}}\right) - N_{\text{flex}}$

Equilibrium in four possible regimes (2)

	Sectors k adjust	Sectors k not adjust
Sector 1 adjusts	$\mathbb{W}_{\text{flex}} - S\psi$	.
Sector 1 not adjust	.	.

Flexible price benchmark ($\psi = 0$):

- $p_1 = \frac{W}{A_1}$ and $p_k = W$
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- Flex-price welfare:
  $\mathbb{W}_{\text{flex}} = \ln\left(C_{\text{flex}}\right) - N_{\text{flex}}$

Only sector 1 adjusts:

- $p_1 = \frac{W}{A_1}$ and $p_k = p_k^{ss} = 1$

Equilibrium in four possible regimes (2)

	Sectors k adjust	Sectors k not adjust
Sector 1 adjusts	$\mathbb{W}_{\text{flex}} - S\psi$	.
Sector 1 not adjust	.	.

Flexible price benchmark ($\psi = 0$):

- $p_1 = \frac{W}{A_1}$ and $p_k = W$
- Key object: relative price

$$\left(\frac{p_1}{p_k}\right)_{\text{flex}} = \frac{1}{A_1}$$

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- Flex-price welfare:

$\mathbb{W}_{\text{flex}} = \ln\left(C_{\text{flex}}\right) - N_{\text{flex}}$

Only sector 1 adjusts:

- $p_1 = \frac{W}{A_1}$ and $p_k = p_k^{ss} = 1$
- Relative price:

$$\left(\frac{p_1}{p_k}\right) = \frac{W}{A_1}$$

Equilibrium in four possible regimes (2)

	Sectors k adjust	Sectors k not adjust
Sector 1 adjusts	$\mathbb{W}_{\text{flex}} - S\psi$	.
Sector 1 not adjust	.	.

Flexible price benchmark ($\psi = 0$):

- $p_1 = \frac{W}{A_1}$ and $p_k = W$
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- Flex-price welfare:
  $\mathbb{W}_{\text{flex}} = \ln\left(C_{\text{flex}}\right) - N_{\text{flex}}$

Only sector 1 adjusts:

- $p_1 = \frac{W}{A_1}$ and $p_k = p_k^{ss} = 1$
- Relative price:

$$\left(\frac{p_1}{p_k}\right) = \frac{W}{A_1}$$

- Replicate flex-price relative price by:
  setting $W = W^{ss} = 1$

Equilibrium in four possible regimes (2)

	Sectors k adjust	Sectors k not adjust
Sector 1 adjusts	$\mathbb{W}_{\text{flex}} - S\psi$	$\mathbb{W}_{\text{flex}} - \psi$
Sector 1 not adjust	.	.

Flexible price benchmark ($\psi = 0$):

- $p_1 = \frac{W}{A_1}$ and $p_k = W$
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- Flex-price welfare:
  $\mathbb{W}_{\text{flex}} = \ln\left(C_{\text{flex}}\right) - N_{\text{flex}}$

Only sector 1 adjusts:

- $p_1 = \frac{W}{A_1}$ and $p_k = p_k^{ss} = 1$
- Relative price:

$$\left(\frac{p_1}{p_k}\right) = \frac{W}{A_1}$$

- Replicate flex-price relative price by: setting $W = W^{ss} = 1$
- Welfare under optimal policy:
  $\mathbb{W}_{\text{only 1 adjusts}} = \mathbb{W}_{\text{flex}} - \psi$

Equilibrium in four possible regimes (2)

	Sectors k adjust	Sectors k not adjust
Sector 1 adjusts	$\mathbb{W}_{\text{flex}} - S\psi$	$\mathbb{W}_{\text{flex}} - \psi$
Sector 1 not adjust	$\mathbb{W}_{\text{flex}} - (S-1)\psi$	.

Flexible price benchmark ($\psi = 0$):

- $p_1 = \frac{W}{A_1}$ and $p_k = W$
- Key object: relative price

$$\left(\frac{p_1}{p_k}\right)_{\text{flex}} = \frac{1}{A_1}$$

- $C_{\text{flex}} = A_1^{1/S}/S$; and $N_{\text{flex}} = 1$
- Flex-price welfare: $\mathbb{W}_{\text{flex}} = \ln\left(C_{\text{flex}}\right) - N_{\text{flex}}$

Only sectors k adjust:

- Symmetric.

Equilibrium in four possible regimes (3)

	Sectors k adjust	**Sectors k not adjust**
Sector 1 adjusts	$\mathbb{W}_{\text{flex}} - S\psi$	$\mathbb{W}_{\text{flex}} - \psi$
Sector 1 not adjust	$\mathbb{W}_{\text{flex}} - (S-1)\psi$	$\cdot$

Flexible price benchmark ($\psi = 0$):

- $p_1 = \frac{W}{A_1}$ and $p_k = W$
- Key object: relative price

$$\left(\frac{p_1}{p_k}\right)_{\text{flex}} = \frac{1}{A_1}$$

- $C_{\text{flex}} = A_1^{1/S}/S$; and $N_{\text{flex}} = 1$
- Flex-price welfare: $\mathbb{W}_{\text{flex}} = \ln\left(C_{\text{flex}}\right) - N_{\text{flex}}$

None adjust:

- $p_1 = p_1^{ss} = 1$ and $p_k = p_k^{ss} = 1$

Equilibrium in four possible regimes (3)

	Sectors k adjust	**Sectors k not adjust**
Sector 1 adjusts	$\mathbb{W}_{\text{flex}} - S\psi$	$\mathbb{W}_{\text{flex}} - \psi$
Sector 1 not adjust	$\mathbb{W}_{\text{flex}} - (S-1)\psi$	$\cdot$

Flexible price benchmark ($\psi = 0$):

- $p_1 = \frac{W}{A_1}$ and $p_k = W$
- Key object: relative price

$$\left(\frac{p_1}{p_k}\right)_{\text{flex}} = \frac{1}{A_1}$$

- $C_{\text{flex}} = A_1^{1/S}/S$; and $N_{\text{flex}} = 1$
- Flex-price welfare:

$$\mathbb{W}_{\text{flex}} = \ln\left(C_{\text{flex}}\right) - N_{\text{flex}}$$

None adjust:

- $p_1 = p_1^{ss} = 1$ and $p_k = p_k^{ss} = 1$
- Relative price:

$$\left(\frac{p_1}{p_k}\right) = 1 \neq \left(\frac{p_1}{p_k}\right)_{\text{flex}}$$

Equilibrium in four possible regimes (3)

	Sectors k adjust	Sectors k not adjust
Sector 1 adjusts	$\mathbb{W}_{\text{flex}} - S\psi$	$\mathbb{W}_{\text{flex}} - \psi$
Sector 1 not adjust	$\mathbb{W}_{\text{flex}} - (S-1)\psi$	$\cdot$

Flexible price benchmark ($\psi = 0$):

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$$\left(\frac{p_1}{p_k}\right)_{\text{flex}} = \frac{1}{A_1}$$

- $C_{\text{flex}} = A_1^{1/S}/S$; and $N_{\text{flex}} = 1$
- Flex-price welfare:
  $\mathbb{W}_{\text{flex}} = \ln\left(C_{\text{flex}}\right) - N_{\text{flex}}$

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- $p_1 = p_1^{ss} = 1$ and $p_k = p_k^{ss} = 1$
- Relative price:

$$\left(\frac{p_1}{p_k}\right) = 1 \neq \left(\frac{p_1}{p_k}\right)_{\text{flex}}$$

- Cannot replicate flex-price

Equilibrium in four possible regimes (3)

	Sectors k adjust	**Sectors k not adjust**
Sector 1 adjusts	$\mathbb{W}_{\text{flex}} - S\psi$	$\mathbb{W}_{\text{flex}} - \psi$
Sector 1 not adjust	$\mathbb{W}_{\text{flex}} - (S-1)\psi$	$\cdot$

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- Flex-price welfare:

  $\mathbb{W}_{\text{flex}} = \ln\left(C_{\text{flex}}\right) - N_{\text{flex}}$

None adjust:

- $p_1 = p_1^{ss} = 1$ and $p_k = p_k^{ss} = 1$
- Relative price:

$$\left(\frac{p_1}{p_k}\right) = 1 \neq \left(\frac{p_1}{p_k}\right)_{\text{flex}}$$

- Cannot replicate flex-price
- Upside: no menu costs!

Equilibrium in four possible regimes (3)

	Sectors k adjust	**Sectors k not adjust**
Sector 1 adjusts	$\mathbb{W}_{\text{flex}} - S\psi$	$\mathbb{W}_{\text{flex}} - \psi$
Sector 1 not adjust	$\mathbb{W}_{\text{flex}} - (S-1)\psi$	$-\ln\left(S - 1 + 1/A_1\right) - 1$

Flexible price benchmark ($\psi = 0$):

- $p_1 = \frac{W}{A_1}$ and $p_k = W$
- Key object: relative price

$$\left(\frac{p_1}{p_k}\right)_{\text{flex}} = \frac{1}{A_1}$$

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- Flex-price welfare:

$$\mathbb{W}_{\text{flex}} = \ln\left(C_{\text{flex}}\right) - N_{\text{flex}}$$

None adjust:

- $p_1 = p_1^{ss} = 1$ and $p_k = p_k^{ss} = 1$
- Relative price:

$$\left(\frac{p_1}{p_k}\right) = 1 \neq \left(\frac{p_1}{p_k}\right)_{\text{flex}}$$

- Cannot replicate flex-price
- Upside: no menu costs!
- Welfare:

$$\mathbb{W}_{\text{none adjust}} = -\ln\left(S - 1 + 1/A_1\right) - 1$$

Proving optimal policy

	Sectors k adjust	Sectors k not adjust
Sector 1 adjusts	$\mathbb{W}_{\text{flex}} - S\psi$	$\mathbb{W}_{\text{flex}} - \psi$
Sector 1 not adjust	$\mathbb{W}_{\text{flex}} - (S-1)\psi$	$-\ln\left(S - 1 + 1/A_1\right) - 1$

Lemma 1: If adjusting, only shocked sectors should adjust

$$\mathbb{W}_{\text{only 1 adjusts}} > \mathbb{W}_{\text{all adjust}}, \mathbb{W}_{\text{only } k \text{ adjust}}$$

Proving optimal policy

▸ adjustment externalities

	Sectors k adjust	Sectors k not adjust
Sector 1 adjusts	$\mathbb{W}_{\text{flex}} - S\psi$	$\mathbb{W}_{\text{flex}} - \psi$
Sector 1 not adjust	$\mathbb{W}_{\text{flex}} - (S-1)\psi$	$-\ln\left(S - 1 + 1/A_1\right) - 1$

Lemma 1: If adjusting, only shocked sectors should adjust

$$\mathbb{W}_{\text{only 1 adjusts}} > \mathbb{W}_{\text{all adjust}}, \mathbb{W}_{\text{only } k \text{ adjust}}$$

Lemma 2: $\exists\, \bar{A}$ such that

$$\mathbb{W}_{\text{only 1 adjusts}} > \mathbb{W}_{\text{none adjust}}$$

iff $A_1 > \bar{A}$. Furthermore, $\bar{A}$ is increasing in ψ.

Formally: Social planner's problem

back

$$\max_{X \in \{A,B,C,D\}} \mathbb{U}^X$$

$$\mathbb{U}^A = \left\{ \begin{array}{cc} \max\limits_{M} & \ln[M] - M\left[S - 1 + 1/\gamma\right] \\ \text{s.t.} & \min(\gamma\lambda_1, \lambda_2) \leq M \leq \max(\gamma\lambda_1, \lambda_2) \end{array} \right\}$$

$$\mathbb{U}^B = \left\{ \ln\left[\frac{1}{S}\gamma^{1/S}\right] - 1 - \psi \right\}$$

$$\mathbb{U}^C = \left\{ \begin{array}{cc} \max\limits_{M} & \ln\left[\left(\frac{\gamma}{S}\right)^{\frac{1}{S}} \cdot M^{\frac{S-1}{S}}\right] - \left[(S-1)M + \frac{1}{S}\right] - \frac{1}{S}\psi \\ \text{s.t.} & \lambda_1 < M < \min(\gamma\lambda_1, \lambda_2) \end{array} \right\}$$

$$\mathbb{U}^D = \left\{ \begin{array}{cc} \max\limits_{M} & \ln\left[S^{\frac{1-S}{S}} M^{\frac{1}{S}}\right] - \left[\frac{S-1}{S} + \frac{M}{\gamma}\right] - \frac{S-1}{S}\psi \\ \text{s.t.} & \max(\gamma\lambda_1, \lambda_2) < M < \gamma\lambda_2 \end{array} \right\}$$

where $\lambda_1 = \frac{1}{S}\left(1 - \sqrt{\psi}\right), \quad \lambda_2 = \frac{1}{S}\left(1 + \sqrt{\psi}\right)$

Adjustment externalities

back

Example: Social planner's *constrained* problem for "neither adjust"

$$\max_{M} U\left(C(M), N(M)\right) \tag{1}$$
$$\text{s.t. } D_1^{\text{adjust}} < D_1^{\text{no adjust}} \tag{2}$$
$$D_k^{\text{adjust}} < D_k^{\text{no adjust}} \tag{3}$$

$\implies M^*_{\text{unconstrained}}$

Social planner's *unconstrained* problem: maximize (1), without constraints

$\implies M^*_{constrained}$

Adjustment externality: $M^*_{\text{unconstrained}} \neq M^*_{\text{constrained}}$

Alternative menu cost formulations

back

Labor costs: Welfare mechanism is *higher labor*

$$\text{profits}_i - W\psi \cdot \chi_i$$
$$\implies N = \sum n_i + \psi \sum \chi_i$$

Real resource cost: Welfare mechanism is *lower consumption*

$$\text{profits}_i \cdot (1 - \psi \cdot \chi_i)$$
$$\implies C = Y\left(1 - \psi \sum_i \chi_i\right)$$

Direct utility cost: Welfare mechanism is *direct*

$$\text{utility} - \psi \cdot \sum \chi_i$$

Asymmetric menu costs

back

Recall:

$$p_i = \frac{W}{A_i}$$

Suppose $A_i \uparrow$. Then either:

1. $p_i \downarrow$
2. $W \uparrow$
   - But then $p_j \uparrow$

Suppose $A_i \downarrow$. Then either:

1. $p_i \uparrow$
2. $W \downarrow$
   - But at least then $p_j \downarrow$

More Calvo math

back

Nominal wage targeting:

$$\hat{W} = 0$$

$$\hat{p}_1(A) = -\hat{\gamma}$$

$$\hat{p}_k(A) = 0$$

$$\hat{P} = -\frac{1}{S}(1-\theta)\hat{\gamma}$$

$$\hat{C} = \frac{1}{S}(1-\theta)\hat{\gamma}$$

$$\hat{N} = -\frac{1}{S}\theta\hat{\gamma}$$

Inflation targeting:

$$\hat{W} = \frac{\hat{\gamma}}{S}$$

$$\hat{p}_1(A) = -\hat{\gamma} + \frac{1}{S}\hat{\gamma}$$

$$\hat{p}_k(A) = \frac{\hat{\gamma}}{S}$$

$$\hat{P} = 0$$

$$\hat{C} = \hat{C}^f = \frac{\hat{\gamma}}{S}$$

$$\hat{N} = \hat{N}^f = 0$$

“Generalized multisector Rotemberg”

back

"Generalized multisector Rotemberg"

back

Calvo is isomorphic to Rotemberg menu cost model (Nisticò 2007)

- Rotemberg quadratic menu costs:

$$\psi \cdot (p_i - p_i^{ss})^2 \mathbb{I}\{p_i \neq p_i^{ss}\}$$

“Generalized multisector Rotemberg”

back

Calvo is isomorphic to Rotemberg menu cost model (Nisticò 2007)

- Rotemberg quadratic menu costs:

$$\psi \cdot (p_i - p_i^{ss})^2 \mathbb{I}\{p_i \neq p_i^{ss}\}$$

- Contrast with *nonconvex* menu costs:

$$\psi \cdot \mathbb{I}\{p_i \neq p_i^{ss}\}$$

"Generalized multisector Rotemberg"

back

Calvo is isomorphic to Rotemberg menu cost model (Nisticò 2007)

- Rotemberg quadratic menu costs:

$$\psi \cdot (p_i - p_i^{ss})^2 \mathbb{I}\{p_i \neq p_i^{ss}\}$$

- Contrast with *nonconvex* menu costs:

$$\psi \cdot \mathbb{I}\{p_i \neq p_i^{ss}\}$$

Difference in optimal policy comes from convexity

“Generalized multisector Rotemberg”

back

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Sticky wages: monopsony

back

Sticky prices model:
differentiated output + homogenous labor

$$p_1 = \frac{W}{A_1}$$
$$p_k = \frac{W}{A_k}$$

With shock to A_1, want:

- p_1 adjusts
- W stabilized, so p_k doesn't have to change

Sticky wages: monopsony

▸ back

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Monopsony sticky wage model:
homogeneous output + differentiated labor

$$P = \frac{W_1}{A_1}$$
$$P = \frac{W_k}{A_k}$$
$$W_1 = W_k$$

With shock to A_1, want:

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Sticky wages: monopsony

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- P adjust, so $W_1 = W_k$ doesn't have to adjust

Monopsony model is anti-Keynesian: inverted NKPC (Rowe 2014; Dennery 2021)

Sticky wages

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Sticky wages

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With shock to A_1, want:

- p_1 adjusts
- W stabilized, so p_k doesn't have to change

Standard sticky wage model:
differentiated output + *differentiated* labor

$$p_1 = \frac{W_1}{A_1}$$
$$p_k = \frac{W_k}{A_k}$$
$$W_1 = W_k$$

With shock to A_1, want:

- p_1 adjusts, so $W_1 = W_k = p_k$ doesn't have to adjust
- Wages, $W_1 = W_k$, stabilized

Sticky wages *and sticky prices*

back

- Suppose ψ_P if any *price* p_i changes
- Suppose ψ_W if any *wage* W_i changes

Model:

$$p_1 = \frac{W_1}{A_1}$$

$$p_k = \frac{W_k}{A_k}$$

$$W_1 = W_k$$

Sticky wages *and sticky prices*

back

- Suppose ψ_P if any *price* p_i changes
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$$W_1 = W_k$$

Shock: $A_1 \uparrow$

Sticky wages *and sticky prices*

back

- Suppose ψ_P if any *price* p_i changes
- Suppose ψ_W if any *wage* W_i changes

Model:

$$p_1 = \frac{W_1}{A_1}$$

$$p_k = \frac{W_k}{A_k}$$

$$W_1 = W_k$$

Shock: $A_1 \uparrow$

1. **Option 1:** p_1 adjusts
   - ψ_P

Sticky wages *and sticky prices*

back

- Suppose ψ_P if any *price* p_i changes
- Suppose ψ_W if any *wage* W_i changes

Model:

$$p_1 = \frac{W_1}{A_1}$$

$$p_k = \frac{W_k}{A_k}$$

$$W_1 = W_k$$

Shock: $A_1 \uparrow$

1. **Option 1:** p_1 adjusts
   - ψ_P
2. **Option 2:** W_1 adjusts
   $\implies W_k$ adjusts $\implies p_k$ adjusts
   - $(S-1)\psi_P + S\psi_W$

Sticky wages *and sticky prices*

back

- Suppose ψ_P if any *price* p_i changes
- Suppose ψ_W if any *wage* W_i changes

Model:

$$p_1 = \frac{W_1}{A_1}$$

$$p_k = \frac{W_k}{A_k}$$

$$W_1 = W_k$$

Shock: $A_1 \uparrow$

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2. **Option 2:** W_1 adjusts
   $\implies W_k$ adjusts $\implies p_k$ adjusts
   - $(S-1)\psi_P + S\psi_W$
3. **Option 3:** p_k adjusts
   $\implies W_k$ adjusts
   - $(S-1)\psi_W$ and $W_1 \neq W_k$

Sticky wages *and sticky prices*

back

- Suppose ψ_P if any *price* p_i changes
- Suppose ψ_W if any *wage* W_i changes

Model:

$$p_1 = \frac{W_1}{A_1}$$

$$p_k = \frac{W_k}{A_k}$$

$$W_1 = W_k$$

Shock: $A_1 \uparrow$

1. **Option 1:** p_1 adjusts
   - ψ_P
2. **Option 2:** W_1 adjusts $\implies W_k$ adjusts $\implies p_k$ adjusts
   - $(S-1)\psi_P + S\psi_W$
3. **Option 3:** p_k adjusts $\implies W_k$ adjusts
   - $(S-1)\psi_W$ and $W_1 \neq W_k$

Optimal policy: p_1 adjusts, $W = W_1 = W_k$ stable

Optimal policy is not really about selection effects

back

The existence (or not) of selection effects in menu cost models is an important question in the literature, due to the argument that selection effects reduce monetary non-neutrality relative to models with time-dependent pricing like the Calvo model (Golosov and Lucas 2007; Caballero and Engel 2007; Carvalho and Kryvtsov 2021; Karadi, Schoenle and Wursten 2022). The question this literature generally considers is: in response to a *monetary policy shock*, how much is real output affected? On the other hand, under optimal monetary policy naturally there are no monetary shocks.

However, for the main mechanism we highlight in this paper – a "menu cost channel of optimal monetary policy" – the existence or not of selection effects plays little role. This can be seen by considering two model variants:

1. A menu cost model without selection effects, where firms always set price equal to nominal marginal cost but must pay a menu cost if doing so

Heterogeneity: a monetary "least-cost avoider principle"

back

Proposition 5: Suppose sector i has mass S_i and menu cost ψ_i. Suppose further

$$S_1\psi_1 < \sum_{k>1} S_k\psi_k.$$

Then optimal policy is exactly as in proposition 1, modulo changes in $\bar{A}$.

- *Proof:* Follows exactly as in proof of proposition 1.

Heterogeneity: a monetary "least-cost avoider principle"

▸ back

Proposition 5: Suppose sector i has mass S_i and menu cost ψ_i. Suppose further

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- *Proof:* Follows exactly as in proof of proposition 1.

Interpretation 1: monetary "least-cost avoider principle"

Interpretation 2: "stabilizing the stickiest price"

Multiple shocks: general case

back

Proposition 7: Consider an arbitrary set of productivity shocks to the baseline model, $\{A_1, ..., A_S\}$.

1. Conditional on sectors $\Omega \subseteq \{1, ..., S\}$ adjusting, optimal policy is given by setting $M = M^*_\Omega \equiv \frac{S-\omega}{\sum_{i \notin \Omega} \frac{1}{A_i}}$, where $\omega \equiv |\Omega|$.
2. The optimal set of sectors that should adjust, Ω^*, is given by comparing welfare under the various possibilities for Ω, using $\mathbb{W}^*_\Omega$ defined in the paper.
3. Nominal wage targeting is exactly optimal if the set of sectors which should not adjust are unshocked: $A_i = 1 \ \forall i \notin \Omega^*$.

Multiple shocks

back

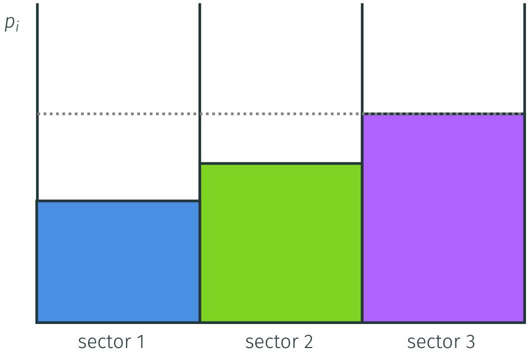
Proposition 6: Suppose:

1. Some strict subset $\Omega \subset \{1, \ldots, S\}$ of sectors is shocked, with "heterogeneous enough" $A_i \neq 1$ for all shocked sectors.

Multiple shocks

back

Recall: $p_i^* = MC_i = \frac{W}{A_i}$



Proposition 6: Suppose:

1. Some strict subset $\Omega \subset \{1, ..., S\}$ of sectors is shocked, with "heterogeneous enough" $A_i \neq 1$ for all shocked sectors.

Then optimal policy sets $W = W^{ss}$.

Price adjustment frequency tracks inflation in the timeseries

▸ back

Calvo/TDP models: frequency of price adjustment is exogenous to inflation

Menu cost models: frequency of price adjustment ↑ if inflation ↑

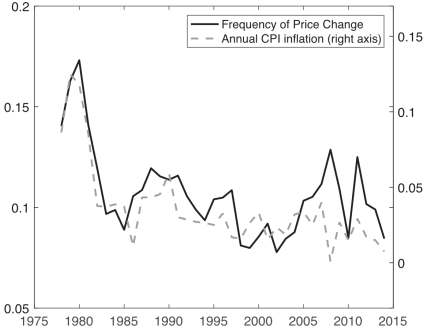


FIGURE XIV

Frequency of Price Change in U.S. Data

Figure 3: Nakamura et al (2018)

Price adjustment frequency tracks inflation in the timeseries

back

Calvo/TDP models: frequency of price adjustment is exogenous to inflation

Menu cost models: frequency of price adjustment ↑ if inflation ↑

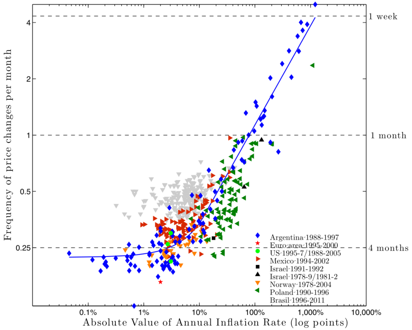


FIGURE VI

The Frequency of Price Changes (λ) and Expected Inflation: International Evidence

Figure 3: Alvarez et al (2018)

Price adjustment frequency tracks inflation in the timeseries

▸ back

Calvo/TDP models: frequency of price adjustment is exogenous to inflation

Menu cost models: frequency of price adjustment ↑ if inflation ↑

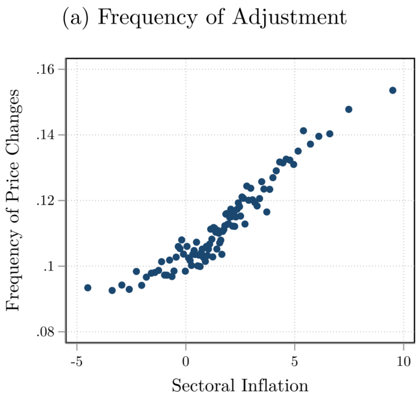


Figure 3: Blanco et al (2022)

Price adjustment frequency tracks inflation in the timeseries

back

Calvo/TDP models: frequency of price adjustment is exogenous to inflation

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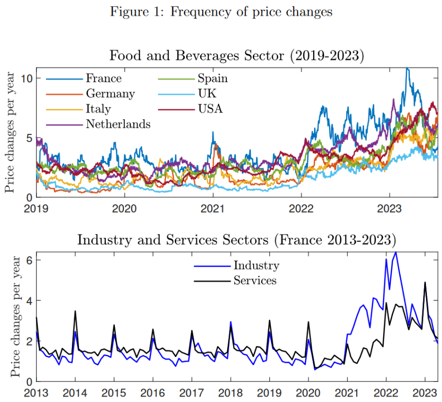

Figure 3: Cavallo et al (2023)

Evidence of inaction regions

Figure 8
The Distribution of the Size of Price Changes in the United States