Monetary Policy Implications of State-Dependent Prices and Wages

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The views expressed here are personal and do not necessarily coincide with official ECB, Eurosystem, or Banco de España views.

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Motivation

- **Nominal rigidity** is a key feature of most monetary models
  - Standard **time-dependent** models: Calvo '83, Rotemberg '82, Taylor '79
- Golosov-Lucas (2007) **state dependent (SD)** model, based on **menu costs**, implies **monetary shocks are almost neutral**
  - Due to *"selection"*: the most misaligned prices get reoptimized, so aggregate price level is more flexible than a Calvo model implies

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  - Due to *"selection"*: the most misaligned prices get reoptimized, so aggregate price level is more flexible than a Calvo model implies
- But newer SD pricing models that **fit microdata better** imply **larger real effects** of money shocks, closer to Calvo
  - *Weaker selection effect* improves micro fit and amplifies real effects: Midrigan '11, Alvarez et al. '11, Dotsey et al. '15, Costain/Nakov ('11/'18)

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- But all this literature assumes **price stickiness is the only friction**
  - Unlike applied DSGEs!!
  - How important is price stickiness relative to other frictions?
  - How does price stickiness interact with other frictions?

This paper

- Study **state dependent prices and wages** simultaneously
- Nominal rigidities following “Logit Price Dynamics” (Costain/Nakov, 2018)
  - Main assumption: **precise decisions are costly**
- Game theoretic approach: *“control costs”*
  - Postulate a cost function for precision
  - Implies mistakes occur in equilibrium
  - If precision is measured by entropy, choices are distributed as a logit
- Market structure following Erceg/Henderson/Levin (2000)
  - Firms are monopolistic suppliers of goods, s.t. Calvo friction
  - Workers are monopolistic suppliers of labor, s.t. Calvo friction
- This paper: Erceg/Henderson/Levin (2000) meets Costain/Nakov (2018)

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  - Firms are monopolistic suppliers of goods, s.t. ~~Calvo friction~~ control costs
  - Workers are monopolistic suppliers of labor, s.t. ~~Calvo friction~~ control costs
  - And allow for idiosyncratic shocks, so we can calibrate to microdata
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Why control costs?

- Barro/Mankiw **menu costs (MCs)**: simple but counterfactual
  - *Micro*: MCs imply no small adjustments (Klenow/Kryvstov '08)
  - *Micro*: MCs imply hazards increase with duration (Klenow/Malin '10)
  - *Micro*: MCs imply std deviation decreases with inflation (Costain/Nakov '11)
  - *Macro*: MCs imply near-neutrality of money (Golosov/Lucas '07)
  - *Case studies*: costs of nominal adjustment relate mostly to **decisions and negotiations** (Zbaracki et al. '04)

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- Representative agent macro: **ignore errors**
  - Study aggregates only, assume errors cancel
- Heterogeneous agent macro: model dynamics of the distribution
  - Fit mean, variance, skewness, kurtosis...
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- **Control costs**: simple, structural model of costly, error-prone choice
  Findings from Costain/Nakov (2018):
  - Errors in *size of adjustment* help explain microdata patterns
  - Errors in *timing of adjustment* help generate monetary non-neutrality

Some related literature

- Interaction of **sticky prices and wages**
  - **Time-dependent**: Erceg/Henderson/Levin '00, Huang/Liu '02, Christiano/Eichenbaum/Evans '05
  - **State-dependent**: Takahashi '17.
    - *No idiosyncratic shocks! Hence no attempt to match microdata!*

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- **State-dependent prices** meet **microdata**
  - Golosov/Lucas '07, Klenow/Malin '10, Nakamura/Steinsson '13, PRISMA ...
- Microdata on **wage adjustment**
  - IWFP (Dickens etal '07), Baratierri/Basu/Gottschalk '11, Sigurdsson/Sigurdsdottir '16, Grigsby/Hurst/Yildirmaz '18

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- **Macro-labor facts**
  - **Phillips curve** slope: Benigno/Ricci '11, Lindé/Trabandt '18, Barnichon/Meesters '18
  - **Real wage** cyclicality is insignificant (Christiano/Eichenbaum/Trabandt '16)
  - **Labor wedge is countercyclical** (Shimer '07, Gali/Gertler/Lopez-S '07)
  - **Price markup** cyclicality is controversial (Nekarda/Ramey '13)
  - **Wage markup is countercyclical** (Gali/Gertler/Lopez-S '07)

Preview of results

- Estimated model implies **significant, quantitatively reasonable real effects** of monetary shocks
- Since wages are a large cost component for firms, **wage rigidity plays a larger role** in generating monetary nonneutrality than price rigidity does
- Since it ignores "selection effects", **Calvo model exaggerates persistence** of real effects, compared with state-dependent model
- When **trend inflation is low**, nominal adjustment is less frequent. Therefore inflation reacts less to monetary shocks, making the **Phillips curve flatter**.

MODEL

Model: monopolistic firms

- **Profits**:
  - Firm i's demand: $Y_{it} \; = \; Y_t P_t^{\epsilon} P_{it}^{-\epsilon}$
  - Firm i's output: $Y_{it} \; = \; A_{it} N_{it}$, where $\log A_{it}$ is AR(1)
  - Profits: $U_t(P_{it}, A_{it}) \; \equiv \; P_{it} Y_{it} - W_t N_{it}$

- **Control variables**:
  - Firm adjusts its price P_{it}
  - Current P_{it} remains in effect until firm sets a new price P'
  - Output and labor are demand driven.

- **Frictions**:
  - Adjustment itself is costless (zero menu costs)
  - But choosing is costly, and **greater precision** requires **more decision time**

Costs of decision-making: price choice

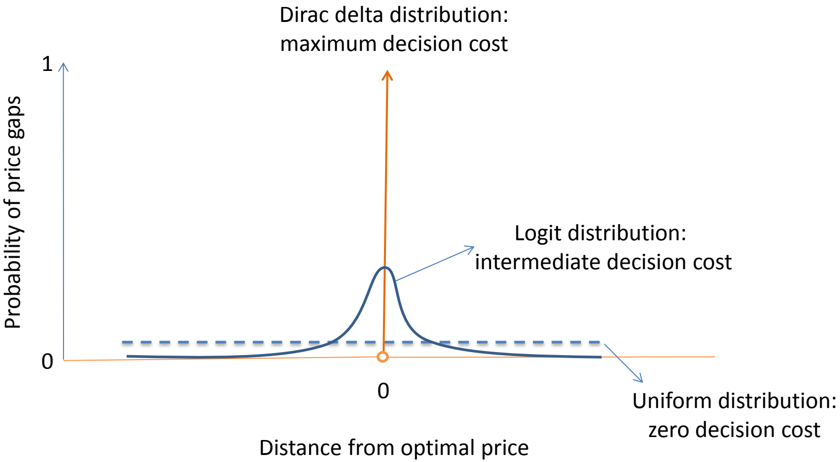
- Think of decisions as probability distributions over alternatives.
- Assume precision is costly.
- Let $\pi(p)$ be a firm's chosen distribution over its log real price p.

Assumption 1. The time cost τ of decision π is:

$$\kappa_\pi \mathcal{D}(\pi || \eta) \equiv \kappa_\pi \int \pi(p) \ln \left(\frac{\pi(p)}{\eta(p)} \right) dp$$

where $\eta(p)$ is an exogenous "default" decision distribution.

Distribution of price adjustments



Costs of decision-making: timing choice

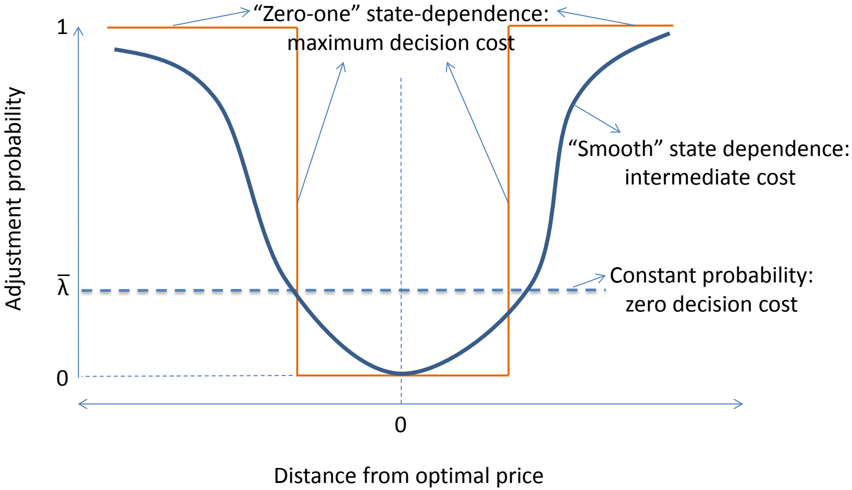
- Let λ be the probability of making a decision in the current period.

Assumption 2. The time cost μ of choosing whether or not to make a decision is:

$$\kappa_\lambda \mathcal{D}\left((\lambda, 1-\lambda)||(\bar{\lambda}, 1-\bar{\lambda})\right) \equiv \kappa_\lambda \left(\lambda \log \frac{\lambda}{\bar{\lambda}} + (1-\lambda) \log \frac{1-\lambda}{1-\bar{\lambda}}\right)$$

where $\bar{\lambda}$ is an exogenous "default" probability.

Reset probability



Bellman equations (real)

- Real value of producing at current firm-specific state (p, a):

$$\begin{aligned} v_t(p,a) &= u_t(p,a) \\ &\quad + \max_{\lambda} \left[(1-\lambda) v_t^e(p,a) + \lambda \tilde{v}_t(a) - w_t \kappa_\lambda \mathcal{D}\left((\lambda, 1-\lambda) || (\bar{\lambda}, 1-\bar{\lambda}) \right) \right] \end{aligned}$$

  - Where $\tilde{v}_t(a)$ is the firm's expected value, conditional on adjustment:

$$\begin{aligned} \tilde{v}_t(a) = \max_{\pi(\tilde{p})} \int \pi(\tilde{p}) v_t^e(\tilde{p}, a) d\tilde{p} - w_t \kappa_\pi \mathcal{D}(\pi || \eta) \\ \text{s.t.} \quad \int \pi(\tilde{p}) d\tilde{p} = 1 \end{aligned}$$

  - And $v_t^e(p, a)$ is the expected value, conditional on unchanged nominal price:

$$v_t^e(p,a) \; = \; E_t \left\{ q_{t,t+1} v_{t+1}(p - i_{t+1}, a') | a \right\}$$

Distribution of actions

- Both price distribution and probability of decision are **weighted logits**.
  - Stahl (1990), Mattsson/Weibull (2002), Matejka/McKay (2015)

- Distribution of prices, conditional on decision:

$$\pi_t(p|a) = \frac{\eta(p)\exp\left(\frac{v_t^e(p,a)}{\kappa_\pi w_t}\right)}{\int \eta(\tilde{p})\exp\left(\frac{v_t^e(\tilde{p},a)}{\kappa w_t}\right) d\tilde{p}}$$

- Probability of making a decision:

$$\lambda_t(p,a) = \frac{\bar{\lambda}}{\bar{\lambda} + (1-\bar{\lambda})\exp\left(\frac{-d_t(p,a)}{\kappa_\lambda w_t}\right)},$$

- Where $d_t(p,a)$ is the real loss from inaction:

$$d_t(p,a) = \tilde{v}_t(a) - v_t^e(p,a)$$

Adding wage stickiness in an analogous way

- Next, do **wage stickiness too**
  - Model wages and prices analogously, as in **Erceg/Henderson/Levin (2000)**
  - Each worker sells a distinct type of labor, as a monopolistic competitor, to many firms
  - So we are **not considering frictions in labor mobility**
  - No search and matching, no unemployment
- Study **effects of monetary shocks** in a control cost model, assuming:
  - Sticky prices and wages
  - Sticky prices, flexible wages
  - Flexible prices, sticky wages
  - Flexible prices and wages
- And compare results to Calvo model

Model: monopolistic supply of labor

- Firm j's labor input is an aggregate of differentiated labor types i:

$$N_{jt} = \left\{ \int_0^1 N_{ijt}^{\frac{\epsilon_n - 1}{\epsilon_n}} di \right\}^{\frac{\epsilon_n}{\epsilon_n - 1}}$$

- Worker i's effective labor N_{ijt} is the product of labor time H_{ijt} and worker-specific productivity Z_{it}:

$$N_{ijt} = Z_{it} H_{ijt}, \quad \text{where} \;\; \log Z_{it} \text{ is AR(1)}$$

- Let W_{it} be worker i's wage per unit of time,
- The aggregate wage index W_t is:

$$W_t = \left\{ \int_0^1 \left(\frac{W_{it}}{Z_{it}} \right)^{1-\epsilon_n} di \right\}^{\frac{1}{1-\epsilon_n}} .$$

Model: monopolistic supply of labor

- Demand for labor time of worker i is:

$$H_{it} \;=\; H_t(W_{it}, Z_{it}) \;\equiv\; Z_{it}^{\epsilon_n - 1} N_t W_t^{\epsilon_n} W_{it}^{-\epsilon_n}.$$

- Households' utility is:

$$u(C_t) - X(H_t + \mu_t^w + \tau_t^w) + \nu(M_t/P_t)$$

where μ_t^w and τ_t^w are time devoted to wage decisions

- Then the marginal value of time is

$$\xi_t \;\equiv\; \frac{P_t}{u'(C_t)} X'(H_t + \mu_t^w + \tau_t^w)$$

Costs of decision-making

- Let $\pi^w(w)$ be a worker's chosen distribution over its log real wage w.
- Let ρ be the probability of making a decision in the current period.

Assumption 3. The time cost τ^w of decision π^w is:

$$\kappa_w \mathcal{D}(\pi^w || \eta^w) \equiv \kappa_w \int \pi^w(w) \ln\left(\frac{\pi^w(w)}{\eta^w(w)}\right) dw$$

where $\eta^w(w)$ is an exogenous "default" decision.

Assumption 4. The time cost μ^w of choosing whether to make a decision is:

$$\kappa_w \mathcal{D}\left((\rho, 1-\rho) || (\bar{\rho}, 1-\bar{\rho})\right) \equiv \kappa_w \left(\rho \log \frac{\rho}{\bar{\rho}} + (1-\rho) \log \frac{1-\rho}{1-\bar{\rho}}\right)$$

where $\bar{\rho}$ is an exogenous "default" probability.

Bellman equation (real)

$$
\begin{aligned}
l_t(w,z) \; = \; & \max_{\tau^w,\mu^w,\rho,\pi^w(\tilde{w})} e^w h_t(w,z) - \frac{X(h_t(w,z)+\tau^w+\mu^w)}{u'(C_t)} \\
& + (1-\rho) l_t^e(w,z) + \rho \int \pi^w(\tilde{w}) l_t^e(\tilde{w},z) d\tilde{w}
\end{aligned}
$$

$$
\text{s.t.} \quad 1 \; = \; \int \pi^w(\tilde{w}) d\tilde{w},
$$

$$
\begin{aligned}
\tau^w \; &= \; \rho \kappa_w \int \pi^w(\tilde{w}) \ln\left(\frac{\pi^w(\tilde{w})}{\eta^w(\tilde{w})}\right) d\tilde{w}, \\
\mu^w \; &= \; \kappa_\rho \left[\rho \ln\left(\frac{\rho}{\bar{\rho}}\right) + (1-\rho)\ln\left(\frac{1-\rho}{1-\bar{\rho}}\right)\right],
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$$
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Distribution of actions

- Both wage distribution and probability of decision are **weighted logits**:
- Distribution of wages, conditional on decision:

$$\pi_t^w(w|z) = \frac{\eta^w(w)\exp\left(\frac{I_t^e(w,z)}{\kappa_w \xi_t}\right)}{\int \eta^w(w')\exp\left(\frac{I_t^e(w',z)}{\kappa_w \xi_t}\right) dw'}$$

- Probability of making a decision:

$$\rho_t(w,z) = \frac{\bar{\rho}}{\bar{\rho} + (1-\bar{\rho})\exp\left(\frac{-d_t^w(w,z)}{\kappa_\rho \xi_t}\right)},$$

- Where $d_t^w(w,z)$ is the real loss from inaction:

$$d_t^w(w,z) = \tilde{I}_t(z) - I_t^e(w,z)$$

Computing general equilibrium

- This is a heterogeneous agent model with **two distributions**:
  - Distribution of prices and productivities across firms
  - Distribution of wages and productivities across firms
  - *(Those are different aspects of heterogeneity from most "HANK" models.)*

- Compute general equilibrium, on finite grids, following **Reiter (2009)**.

- **Step 1. Compute steady-state of heterogeneous agent economy**, without aggregate shocks.

- **Step 2. Linearize the aggregate dynamics** to simulate impulse responses.

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- **Step 1. Compute steady-state of heterogeneous agent economy**, without aggregate shocks.
  - Guess C, N, w
  - Solve for value functions by backwards induction
  - Solve for cross-sectional distributions by simulating forward
  - Check market clearing, update guess.

- **Step 2. Linearize the aggregate dynamics** to simulate impulse responses.
  - Linearize Bellman equation and distributional dynamics.
    - That's two linear equations at **each grid point**!!
  - Solve the rational expectations dynamics using Klein's (2000) algorithm.

RESULTS:

LINEAR LABOR DISUTILITY

$$X(h) = \chi h$$

Simulations and data

- We compare six calibrations (initial parameters from Costain/Nakov '18)
  - **V1: Benchmark. Sticky prices and wages:** $\kappa_\pi = \kappa_\lambda = \kappa_w = \kappa_\rho = 0.017$
  - V2: Semi-flexible prices and sticky wages: $\kappa_\pi = \kappa_\lambda = 0.0017$
  - V3: Flexible prices and sticky wages: $\kappa_\pi = \kappa_\lambda = 0.00017$
  - V4: Sticky prices and semi-flexible wages: $\kappa_w = \kappa_\rho = 0.0017$
  - V5: Sticky prices and flexible wages: $\kappa_w = \kappa_\rho = 0.00017$
  - V6: Flexible prices and flexible wages: $\kappa_\pi = \kappa_\lambda = \kappa_w = \kappa_\rho = 0.00017$
- *Default hazard rates* are $\bar{\lambda} = \bar{\rho} = 0.2$ in all cases
- Also compare each version to a Calvo model with sticky prices and wages, imposing the same frequency of adjustment.

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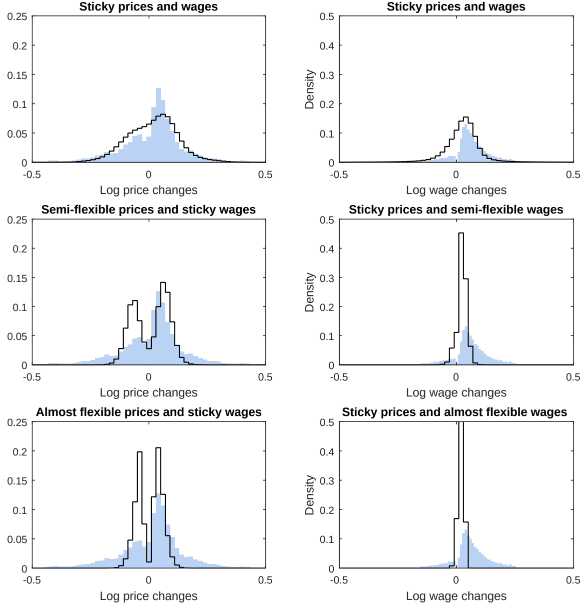
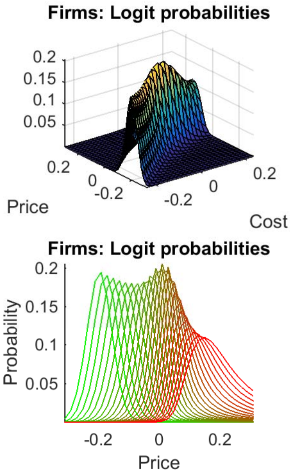
- Also compare each version to a Calvo model with sticky prices and wages, imposing the same frequency of adjustment.

- **Price data**: Cross-sectional distribution of retail price adjustments (after excluding sales) from Dominick's dataset
- **Wage data**: Cross-sectional distribution of annual wage adjustments from IWFP dataset

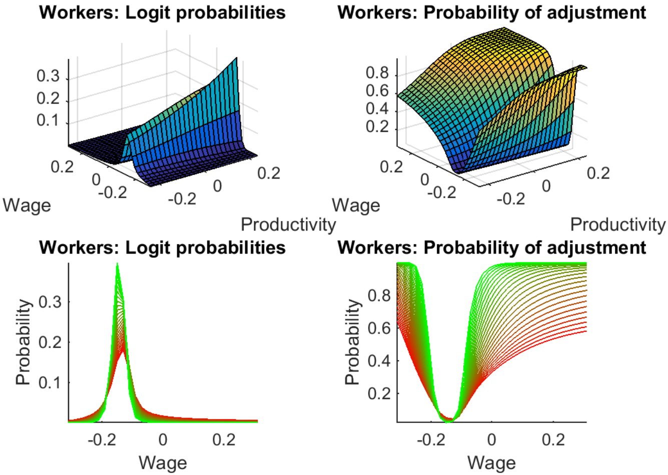
Nonzero price and wage changes: varying decision cost



Price probabilities and adjustment rates: firms (V1)



Wage probabilities and adjustment rates: workers (V1)



Steady-state behavior and decision costs

	V1 Both sticky	V3 Fl-P, St-W	V5 St-P, Fl-W	V6 Both flex.
Frequency and size of adjustments (%):				
Price adj. freq.	10.1	54.4	10.4	54.4
Wage adj. freq.	6.02	6.04	7.28	6.95
Abs($\Delta \ln p$)	8.57	4.76	8.57	4.76
Abs($\Delta \ln w$)	6.14	6.16	1.98	2.29
Costs as % of revenues:				
Price setting costs	0.43	0.01	0.43	0.01
Price timing costs	0.34	0.01	0.34	0.01
Loss w.r.t. full rationality	1.67	0.05	1.67	0.05
Wage setting costs	0.33	0.34	0.01	0.00
Wage timing costs	0.38	0.39	0.01	0.01
Loss w.r.t. full rationality	0.92	0.94	0.01	0.01

Note: Firms' costs stated as percentage of average revenue.

Workers' costs stated as percentage of average labor income.

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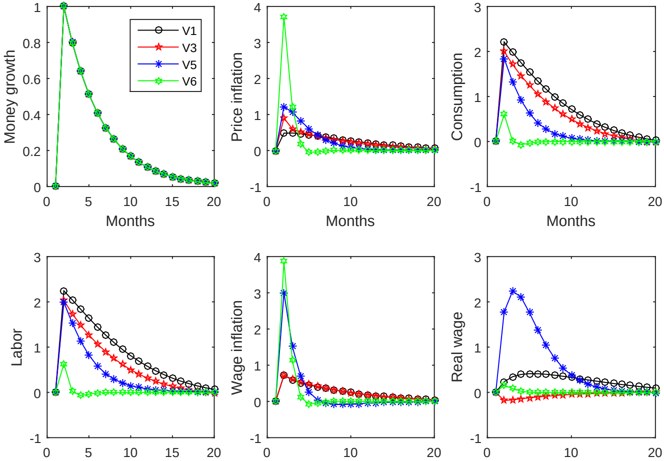
Abs($\Delta \ln w$)	6.14	6.16	1.98	2.29
Costs as % of revenues:				
Price setting costs	0.43	0.01	0.43	0.01
Price timing costs	0.34	0.01	0.34	0.01
Loss w.r.t. full rationality	1.67	0.05	1.67	0.05
Wage setting costs	0.33	0.34	0.01	0.00
Wage timing costs	0.38	0.39	0.01	0.01
Loss w.r.t. full rationality	0.92	0.94	0.01	0.01

Note: Firms' costs stated as percentage of average revenue.

Workers' costs stated as percentage of average labor income.

Money supply shock: effects of price and wage stickiness

V1: sticky, V3: Pflex/Wsticky, V5: Psticky/Wflex, V6: flexible



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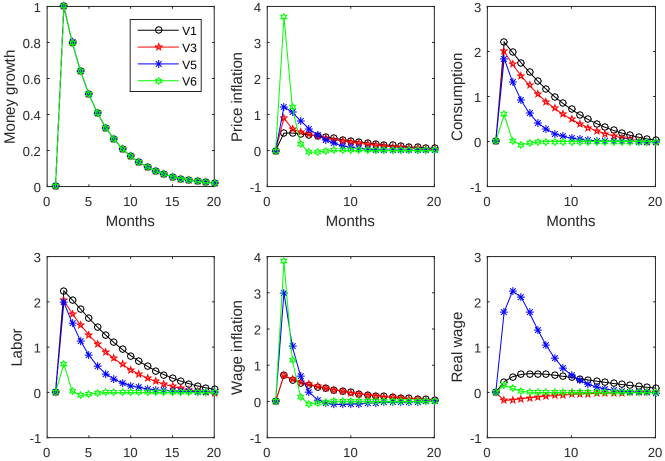
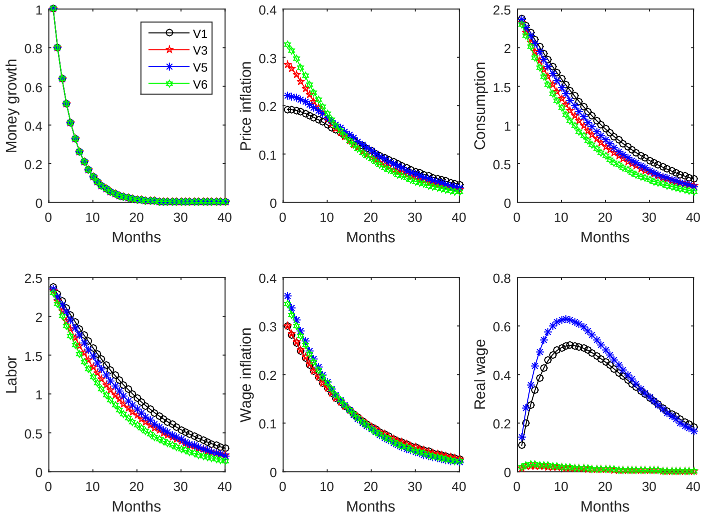


Notice: consumption response **almost as large in V3 as in V1** !

Money supply shock: effects of stickiness (Calvo model)

V1C: sticky, V3C: Pflex/Wsticky, V5C: Psticky/Wflex, V6C: flexible



Main findings: linear case

1. Decreased decision costs for P or W have the expected effects:
   - Make adjustment more frequent
   - Make average adjustment smaller
   - Decrease time devoted to the decision

2. **Linear disutility** of labor supply implies **constant desired wage**, so we really can't compare this version to wage adjustment data

3. **Sticky wages generate more nonneutrality** than sticky prices
   - If W is flexible, monetary stimulus is offset by $\frac{W}{P} \uparrow$
   - Sticky wages + flexible prices generates almost as much persistence as a model where both are sticky

4. Control costs on P and W recovers **roughly half of the persistence** of real effects observed in an analogous Calvo model

RESULTS:

CONVEX LABOR DISUTILITY

$$X(h) = \frac{\chi}{1+\zeta} h^{1+\zeta}, \quad \zeta = 0.5$$

Nonlinear model ($\zeta = 0.5$): parameter estimates

Estimation criterion:

$$\begin{aligned}\text{distance} &= \sqrt{\#_{Dom}}\,||\lambda_{model} - \lambda_{Dom}|| + ||\vec{h}^{w}_{model} - \vec{h}_{Dom}|| \\ &+ \sqrt{\#_{IWFP}}\,||\rho_{model} - \rho_{IWFP}|| + ||\vec{h}^{w}_{model} - \vec{h}^{w}_{IWFP}||,\end{aligned}$$

Estimation results:

Parameters	Prices	Wages
Default hazard	$\bar{\lambda} = 0.2707$	$\bar{\rho} = 0.2317$
Decision noise	$\kappa_{\pi} = \kappa_{\lambda} = 0.0177$	$\kappa_{w} = \kappa_{\rho} = 0.0275$
Productivity process	$\rho_a = 0.644 \quad \sigma_a = 0.0703$	$\rho_z = 0.970 \quad \sigma_z = 0.0574$

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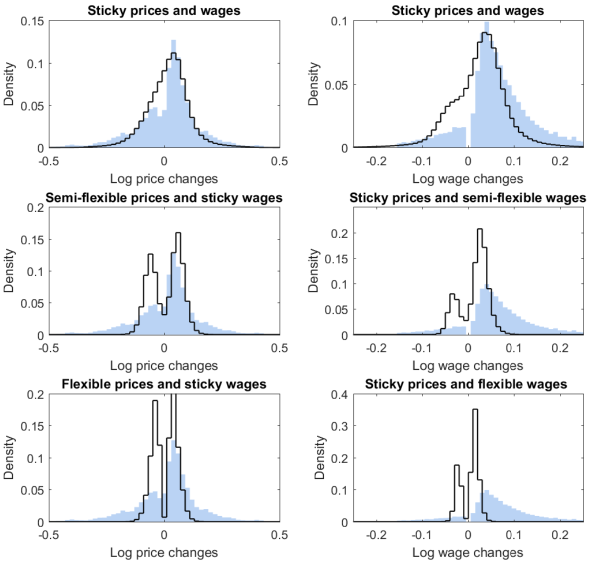
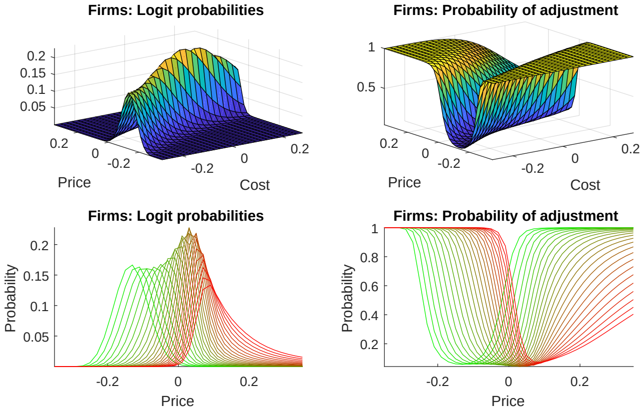
Simulation exercises:

- **V1N**: baseline estimate (sticky)
- **V2N, V3N**: more price flexibility
- **V4N, V4N**: more wage flexibility
- **V6N**: both flexible

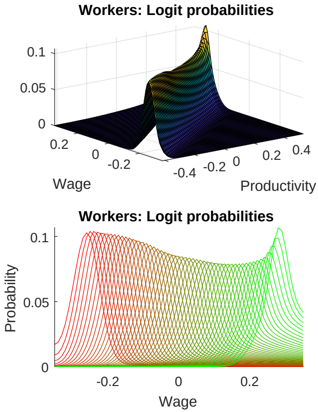
Nonzero price and wage changes: varying decision cost



Price probabilities and adjustment rates: firms (V1)



Wage probabilities and adjustment rates: workers (V1)



Steady-state behavior and decision costs

	V1N Both sticky	V3N Fl-P, St-W	V5N St-P, Fl-W	V6N Both flex.
Frequency and size of adjustments (%):				
Price adj. freq.	10.2	59.5	10.2	59.7
Wage adj. freq.	8.34	8.33	30.8	30.7
Abs($\Delta \ln p$)	6.94	4.53	6.92	4.52
Abs($\Delta \ln w$)	5.50	5.50	1.95	1.96
Costs as % of revenues:				
Price setting costs	0.50	0.07	0.49	0.07
Price timing costs	0.48	0.03	0.48	0.03
Loss w.r.t. full rationality	2.49	1.01	2.48	1.01
Wage setting costs	1.09	1.10	0.08	0.03
Wage timing costs	0.94	0.95	0.03	0.01
Loss w.r.t. full rationality	2.77	2.79	0.29	0.29

Note: Firms' costs stated as percentage of average revenue.

Workers' costs stated as percentage of average labor income.

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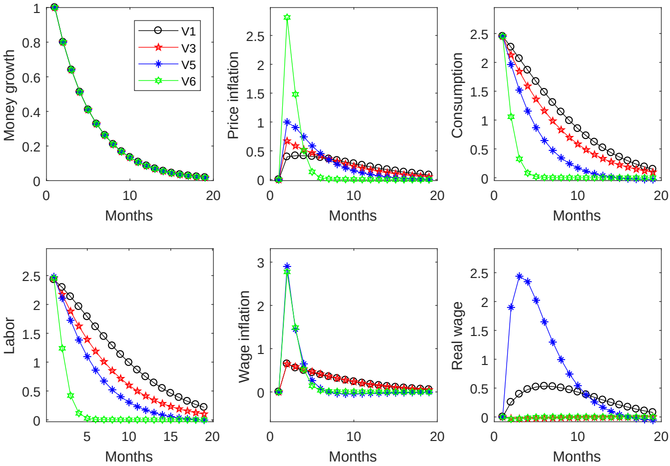

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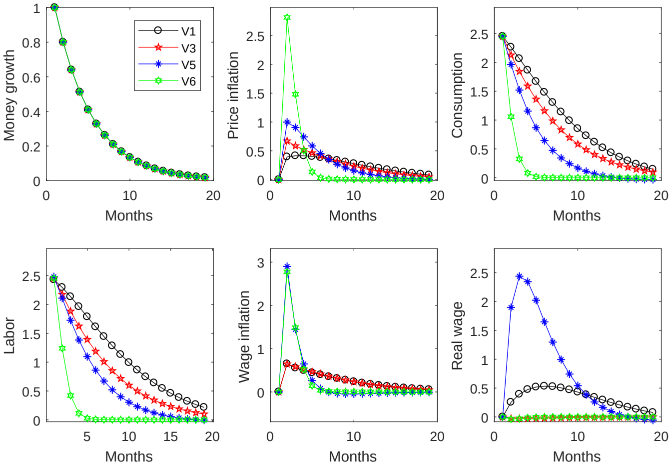
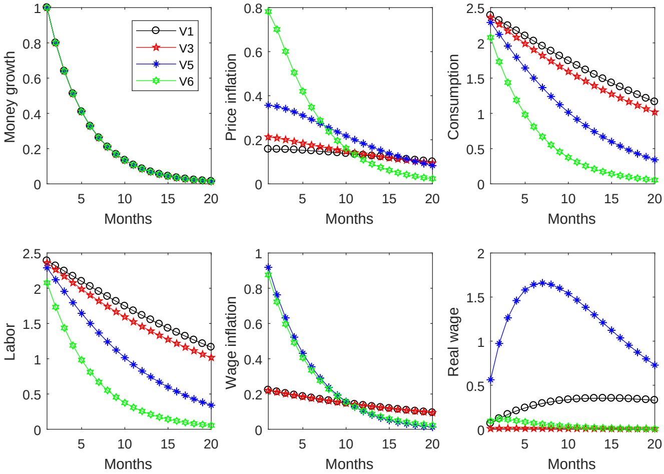


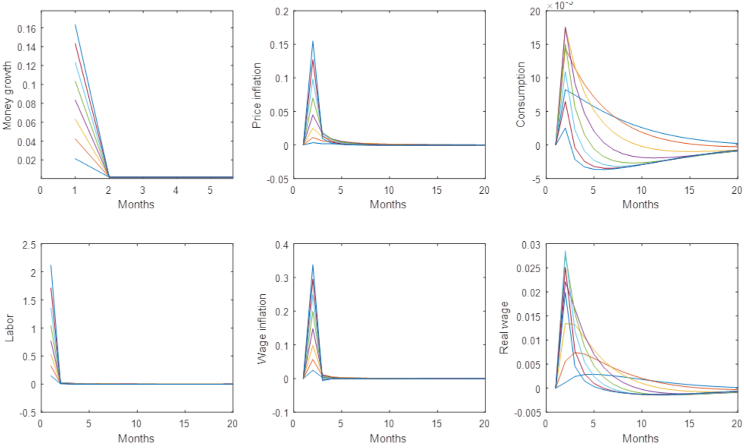
Notice: consumption response **almost as large in V3N as in V1N**!

Money supply shock: effects of stickiness (Calvo model)

V1CN: sticky, V3CN: Pflex/Wsticky, V5CN: Psticky/Wflex, V6CN: flexible



Diminishing returns to monetary stimulus (tentative!)



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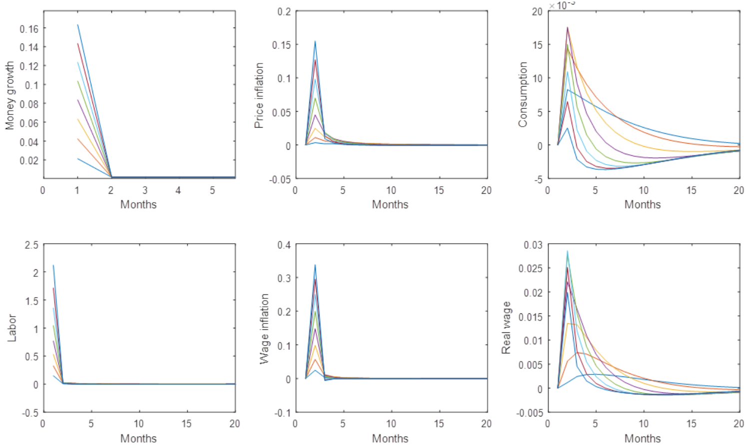
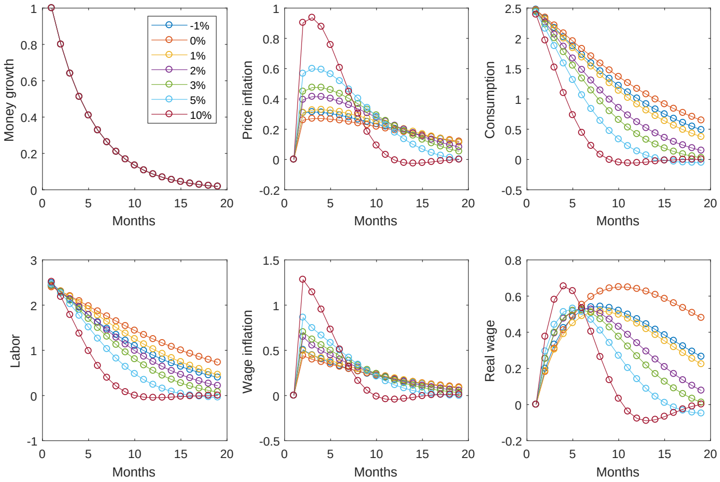
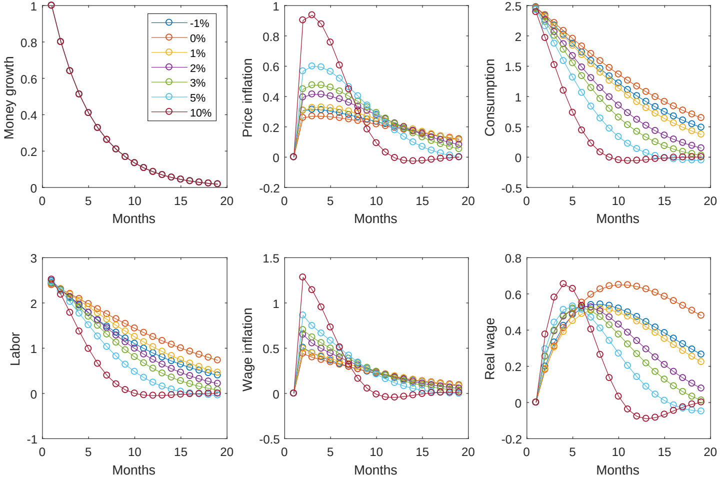


- **Diminishing returns**: greater stimulus is less effective on the margin
- **Cumulative consumption effect maximized** by $\Delta \log M^s \approx 0.05$!

Money supply shock: effects of trend inflation



Money supply shock: effects of trend inflation



- **Phillips curve slope** $= \Delta\pi/\Delta \log H$ **decreases** as inflation declines!
- May be harder to hit inflation target, but money has **stronger effects on real variables**

Effects of trend inflation

	Annual trend inflation rate				
	-1%	0	1%	2%	5%
Frequency and size of adjustments (%):					
Price adj. freq.	9.04	7.53	9.05	10.2	12.5
Wage adj. freq.	7.28	6.95	7.53	8.34	10.8
Abs($\Delta \ln p$)	6.50	6.18	6.59	6.94	7.72
Abs($\Delta \ln w$)	4.91	4.93	5.20	5.50	6.27
Std($\Delta \ln p$)	8.65	8.54	8.80	8.96	9.39
Std($\Delta \ln w$)	6.77	6.82	6.82	6.74	6.55
Phillips multipliers: inflation/employment tradeoffs:					
Multiplier on impact	0.124	0.105	0.126	0.161	0.233
Cumulative multiplier	0.172	0.147	0.195	0.254	0.394

Note: "Phillips multipliers" are ratios of the change in inflation to the change in log employment caused by a money shock.

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Main findings: steady state

1. **Feasible to estimate nonlinear disutility model** by matching steady-state histograms
   - FORTRAN was needed for speed.
2. Good fit to typical size and dispersion of adjustments
   - But histogram excessively smooth, compared with data
   - May still need wider and finer wage grid?
3. **Implied costs of decisions:**
   - Firms spend $\approx 1\%$ of revenue managing prices
   - Workers spend $\approx 2\%$ of time managing wages
4. **Lifetime productivity trend** generates **illusion of downward nominal wage rigidity**
   - Workers have little incentive to make small negative wage changes

Main findings: impulse responses

1. Microfounded model of **nominal price and wage rigidity** generates **substantial real effects** of monetary shocks
   - Estimate V1N: **cumulative Phillips multiplier** ≈ 0.25 at 2% trend inflation
   - Equals Phillips coefficient of Blanchard (2016) in Great Moderation period (controlling for inflation expectations)
2. Calvo framework significantly **exaggerates persistence** of real effects, compared with state-dependent model
3. **Sticky wages generate more nonneutrality** than sticky prices
   - If W is flexible, monetary stimulus is offset by $\frac{W}{P} \uparrow$
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4. **Comparing persistence**:

	V5N St-P, Fl-W	V3N Fl-P, St-W	V1N Both sticky	Calvo Both sticky
Half life of consumption IRF	4	6	8	22

Main findings: nonlinearities

1. **Diminishing returns to monetary stimulus** (tentative)
   - **Diminishing returns**: greater stimulus is less effective on the margin
   - **Cumulative consumption effect maximized** by $\approx 5\%$ increase in money supply!
   - Thereafter, larger increases have a mostly negative impact on consumption

2. **Phillips curve gets flatter** as trend inflation falls
   - Due to state dependence, not downward nominal rigidity!
   - Phillips curve is flattest at zero trend inflation, steeper at higher or lower rates
   - **Cumulative Phillips multiplier** rises from 0.147 at zero trend inflation to 0.394 at 5% annual trend inflation
   - May be harder to hit inflation target, but money has **stronger effects on real variables** when trend inflation is low

EXTENSIONS/RELATED

Control costs: a research agenda

- Simple but widely-applicable model of **costly decisions** as a microfoundation for **sluggish adjustment**
  - For any context where **one control variable** is **intermittently updated**
  - Basically an **error-prone (S,s) model**
  - Similar to "rational inattention", but more tractable state space

- Done so far:
  - Sticky prices (Costain/Nakov JECD 2015, JMCB 2018)
  - Sequential bargaining (Costain 2017, BdE WP1729)
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- To do:
  - PRISMA!!
  - Sticky prices in continuous time
  - Matching and wage bargaining
- Could do:
  - Inventory adjustment
  - Portfolio adjustment
  - Bids/asks in financial markets
  - Adjustment of policy instruments

Sticky prices in continuous time: application to petrol

- Control cost model of sticky prices simplifies further in continuous time
  - I have run some horseraces on different algorithms

- Simple first-order condition linking **optimal price choice** and **optimal adjustment timing**:

$$\log\left(\frac{\pi(p|a)}{\bar{\eta}}\right) = \frac{v(p,a)-\tilde{v}(z)}{\kappa} = \log\left(\frac{\lambda(p,a)}{\bar{\lambda}}\right)$$

- FOC between observables:

$$\log \pi(p|a) = -\log(\lambda(p,a)) + \frac{\bar{\eta}}{\bar{\lambda}}$$

- Testing that requires data on costs
- Spanish data: **daily panel of retail gasoline prices**, plus daily data on international wholesale gasoline price

Deriving matching frictions and wage stickiness from control costs

- Following Cheremukhin/Restrepo/Tutino '12, can **derive matching function** from costly choice of partner
  - Choice across possible partners is governed by a logit
  - Equilibrium between firm and worker decisions resembles a matching function
- Following Costain '17, derive **sticky wage bargain** from costly choice in a sequential bargaining game
  - Both initial wage bargain, and subsequent renegotiations and/or separations, are derived from the same repeated game
- Derive **matching frictions**, **nominal wage rigidity**, and **separations** from the same underlying decision costs; analyze their interactions
  - Equilibrium should lie between the two cases described by Michaillat/Saez '12: fixed tightness / flex prices vs. flex tightness / fixed prices

Thanks for your attention!