Non-Linear Inflation Dynamics In Menu Cost Economies

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Motivation

- Menu costs often invoked as source of price rigidities
  - firms more likely to respond to large aggregate shocks
  - so Phillips curves non-linear
- We show standard menu cost models predict linear Phillips curves
  - when consistent with the distribution of micro price changes
  - for moderate inflation rates observed in advanced economies
- Need implausibly large menu costs, esp with strategic complementarities
  - counterfactually, no comovement btw inflation and frequency of adjustment
  - and very large losses from misallocation from price dispersion

Our Resolution

- Extend multi-product menu cost model
  - strategic complementarities at firm, not product, level
  - low elasticity of substitution between products of a firm

- Model implies less within-firm misallocation from price dispersion
  - require smaller menu costs to reproduce distribution of price changes

- Our model predicts non-linear output responses to monetary shocks
  - in contrast to standard models
  - due to strong response in the frequency of adjustment

Motivating Fact

Inflation and the Frequency of Adjustment

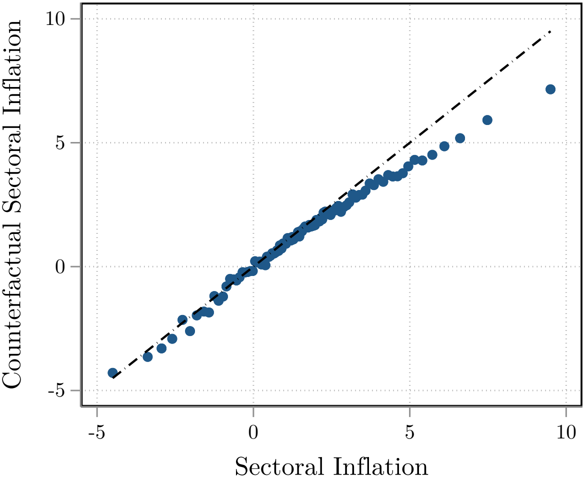
- UK micro-price data underlying the CPI, organized in 71 sectors
  - focus on regular price changes: exclude V-shaped sales $<$ 3 months figure

- Decompose $\pi_t(s)$ extensive and intensive margin (Klenow-Kryvtsov, 2005)

- $\pi_t(s) = \Delta_t(s) f_t(s)$
  - $\Delta_t(s)$: average price change conditional on adjustment
  - $f_t(s)$: fraction of price changes

- Isolate role of intensive margin by computing $\pi_t^c(s) = \Delta_t(s)\bar{f}(s)$
  - $\bar{f}(s)$: average frequency in sector s

Evidence From All Sectors



Extensive margin of price adjustment important at high rates of inflation

table

Single-Product Model

Model Overview

- Consumers: log-linear preferences + cash in advance constraint
  - so $W_t = P_t c_t = M_t$

- Continuum of sectors: Cobb-Douglas aggregator

- Sectoral output: $y_t(s) = \left(\int \left(\frac{y_t(f,s)}{u_t(f,s)} \right)^{\frac{\sigma-1}{\sigma}} \mathrm{d}f \right)^{\frac{\sigma}{\sigma-1}}$

- Firm output: $y_t(f,s) = e_t(s)\, u_t(f,s)\, l_t(f,s)^{\eta}$
  - $e_t(s)$ and $u_t(f,s)$ independent random walks with Gaussian innovations

- Menu costs ξ drawn from $U\left[0, \bar{\xi}\right]$
  - with probability $1-\lambda$ free price change

Parameterization

- Assigned

  – period 1 month

  – $\sigma = 6$ so flexible price markup 1.20, $\eta = 2/3$, $\beta = 0.96$

- Choose menu cost and s.d. firm shocks to match UK micro data

	Data	Model
frequency Δp	0.12	0.12
distribution of Δp		
mean	0.02	0.02
std. dev.	0.19	0.20
kurtosis	3.61	3.65
10^{th} percentile	-0.23	-0.23
25^{th} percentile	-0.08	-0.10
50^{th} percentile	0.03	0.02
75^{th} percentile	0.12	0.14
90^{th} percentile	0.25	0.27

Menu Costs and Misallocation

- Calibrated parameters

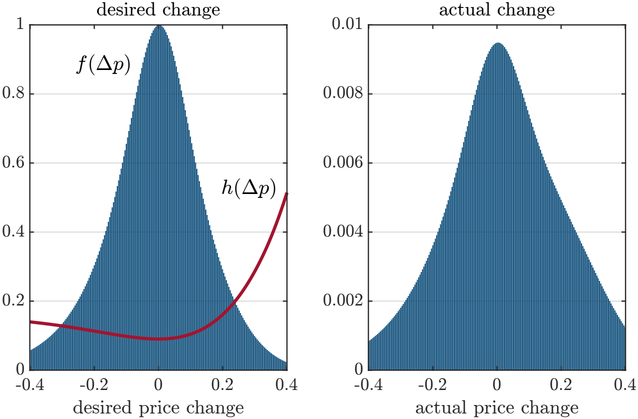
s.d. idios. shocks	σ_u	0.067
prob. free price change	$1-\lambda$	0.091
menu cost rel to avg sales		0.088

- Menu costs much larger than existing estimates ($\approx 1\%$)

- Productivity losses from price dispersion are 21.63%
  - as large as De Loecker–Eeckhout–Unger, Baqaee–Farhi estimates
  - but they capture all distortions, not just menu costs

table

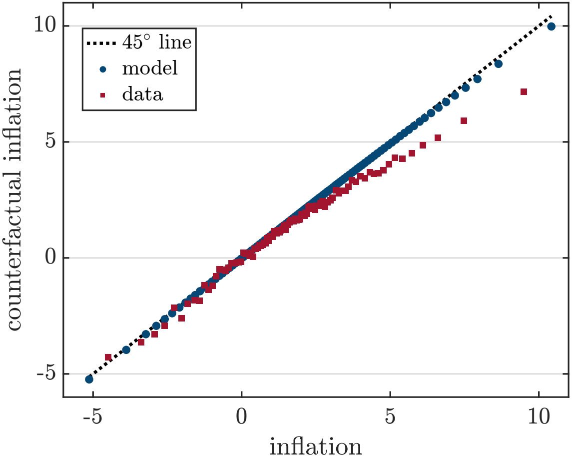
Why Menu Costs So Large?



- Need large probability free Δp to match small $|\Delta p|$
- Need relatively flat hazard to match large $|\Delta p|$

formula

Extensive Margin of Adjustment



Weak extensive margin even at high rates of inflation

table

Multi-Product Model

Overview

- Build on Midrigan (2011) and Alvarez–Lippi (2014) multi-product model
  - firms sell continuum of products
  - product quality shocks $z_{it}(f, s)$, in addition to firm-specific $u_t(f, s)$
  - economies of scope in price adjustment: menu cost $\bar{\xi}$ to change all prices

- Add two ingredients
  - specific factor (e.g. managerial input) mobile across products within firm
  - low elasticity of substitution between products of a given firm

Technology

- Composite good of firm f

$$y_t\left(f,s\right)=\left(\int_0^1\left(\frac{y_{it}\left(f,s\right)}{z_{it}\left(f,s\right)}\right)^{\frac{\gamma-1}{\gamma}}\mathrm{d}i\right)^{\frac{\gamma}{\gamma-1}}$$

- Individual varieties produced using labor and specific factor m_{it}

$$y_{it}(f,s)=e_t\left(s\right)u_t\left(f,s\right)z_{it}\left(f,s\right)m_{it}\left(f,s\right)^{1-\eta}l_{it}\left(f,s\right)^{\eta}$$

  - specific factor mobile across products, fixed at firm level

$$\int m_{it}\left(f,s\right)\mathrm{d}i=1 \qquad \text{vs.} \qquad m_{it}(f,s)=1$$

- Firm production function

$$y_t\left(f,s\right)=e_t\left(s\right)u_t\left(f,s\right)\phi_t\left(f,s\right)l_t\left(f,s\right)^{\eta}$$

Parameterization

- Two economies
  - our model: $\gamma = 1$, $\sigma = 6$, mobile specific factor
  - standard multi-product model: $\gamma = \sigma = 6$, fixed specific factor

	Data	Our model	Standard
frequency Δp	0.12	0.12	0.12
	distribution of Δp		
mean	0.02	0.02	0.03
std. dev.	0.19	0.20	0.20
kurtosis	3.61	3.57	3.51
10^{th} percentile	-0.23	-0.23	-0.23
25^{th} percentile	-0.08	-0.11	-0.09
50^{th} percentile	0.03	0.02	0.04
75^{th} percentile	0.12	0.14	0.16
90^{th} percentile	0.25	0.26	0.26

Menu Costs and Misallocation

- Calibrated parameters

		Our model	Standard
s.d. product shocks	σ_z	0.062	0.058
s.d. firm shocks	σ_u	0.025	0.037
menu cost rel to avg sales		0.024	0.258

- Menu costs in our model closer to the 1% estimates

- Smaller losses from price dispersion: 1.97% (21.24%)

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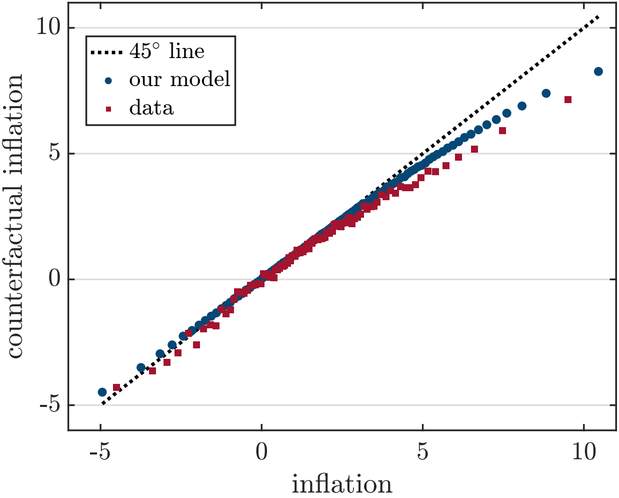
Importance of Extensive Margin



Stronger extensive margin at high inflation, 1/2 of data

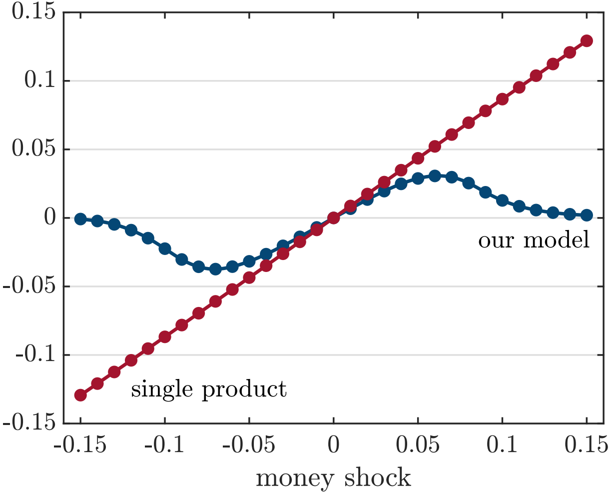
standard table robustness

Real Effects of Monetary Shocks

Impulse Responses to One-Time Shocks

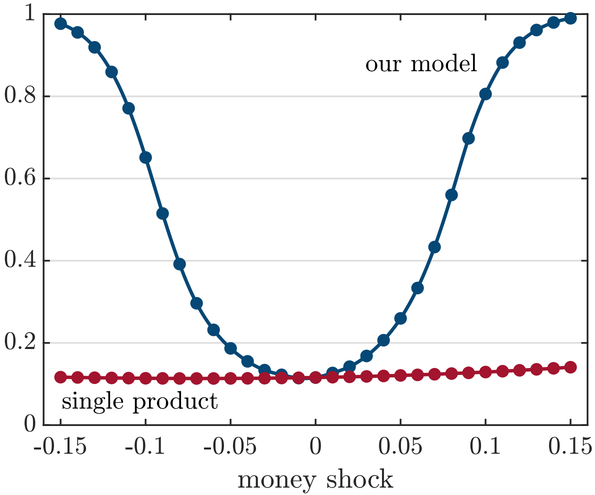
- Response of y_t to one-time, unanticipated, permanent changes in M_t
  - for shocks of different sizes to gauge non-linearity
  - contrast our model to single product model
- Since $P_t y_t = M_t$, larger response of y_t due to slower P_t response

Output Response on Impact

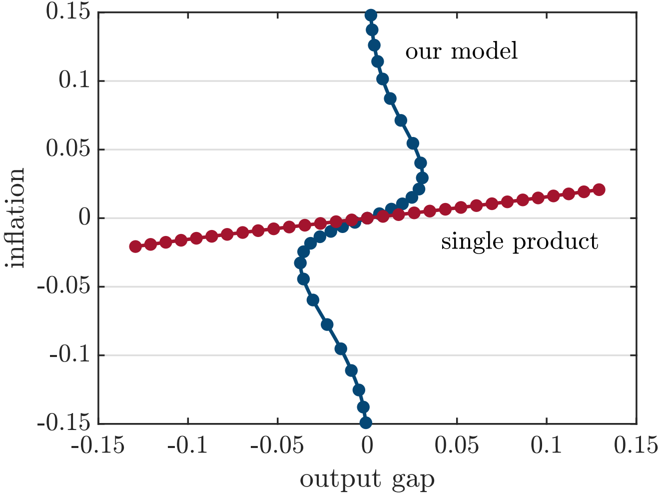


CIR

Frequency of Price Changes on Impact



Non-Linear Phillips Curve

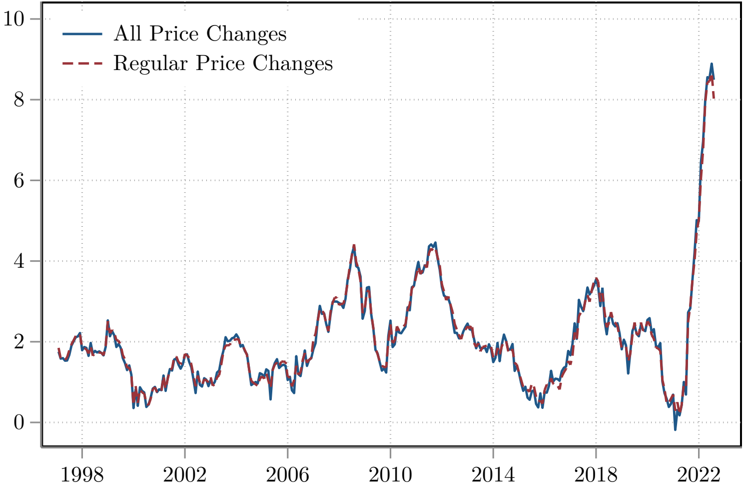


decomposition

Conclusions

- Standard menu cost models predict linear inflation dynamics due to
  - implausibly large menu costs and misallocation from price dispersion
  - counterfactually low of comovement btw inflation and freq of adjustment
- Proposed simple extension to remedy these shortcomings
  - less misallocation from price dispersion inside the firm
- Model reproduces micro price statistics with much smaller menu costs
- Predicts non-linear output responses to monetary shocks

Inflation in UK



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Importance of Extensive Margin

Inflation Volatility

s.d. $\pi_t(s)$	2.87
s.d. $\pi_t^c(s)$	2.51
ratio	0.87

Slope of $\pi_t^c(s)$ to $\pi_t(s)$

all observations	0.80
$\pi_t(s) > 75^{th}$ pct.	0.48
$\pi_t(s) > 90^{th}$ pct.	0.39

All statistics weighted using sectoral expenditure weights.

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Evidence from Other Countries

- Karadi-Reiff (2019)
  - study response of prices to 5% value added tax increase in Hungary
  - frequency price changes up from 13% to 62%
  - show menu cost model with fat-tailed shocks reproduces evidence
- Mexico: Gagnon (2009)
- Argentina: Alvarez-Beraja-Gonzalez-Rozada-Neumayer (2018)
- US: Nakamura-Steinsson (2018)

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Real Marginal Cost Index

- Define real marginal cost index

$$a_t(s) = \frac{W_t}{P_t(s)\, y_t(s)} \left(\frac{y_t(s)}{e_t(s)} \right)^{\frac{1}{\eta}}$$

- If price flexible, $a_t(s) = \eta$

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Standardized Price Changes

- Data organized in 6-digit sectors and items (product categ. within sector)

- Let i be product quote, j be item, $\Delta p_{it}(j)$ log price change if adjust

- Standardized price change (Klenow-Kryvtsov 2008)

$$\hat{\Delta} p_{it}(j) = \frac{\Delta p_{it}(j) - \mu_{\Delta}(j)}{\sigma_{\Delta}(j)} \sigma_{\Delta} + \mu_{\Delta}$$

  - $\mu_{\Delta}(j)$, μ_{Δ}: mean non-zero log price changes
  - $\sigma_{\Delta}(j)$, σ_{Δ}: std. dev. non-zero log price changes

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Demand

- Demand for individual product

$$y_{it}\left(f,s\right)=z_{it}\left(f,s\right)\left(\frac{z_{it}\left(f,s\right)P_{it}\left(f,s\right)}{P_{t}\left(f,s\right)}\right)^{-\gamma}y_{t}\left(f,s\right)$$

- Composite firm price

$$P_{t}\left(f,s\right)\equiv\int P_{it}\left(f,s\right)\frac{y_{it}\left(f,s\right)}{y_{t}\left(f,s\right)}\mathrm{d}i=\left(\int\left(z_{it}\left(f,s\right)P_{it}\left(f,s\right)\right)^{1-\gamma}\mathrm{d}i\right)^{\frac{1}{1-\gamma}}$$

- Labor required to produce bundle $y_{it}(f,s)$

$$l_{t}(f,s)=\left(\int\frac{y_{it}\left(f,s\right)}{e_{t}\left(s\right)u_{t}\left(f,s\right)z_{it}\left(f,s\right)}\mathrm{d}i\right)^{\frac{1}{\eta}}$$

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Markup Dispersion

- Model generates large dispersion in markups, misallocation

cost-weighted average	1.195
sales-weighted average	1.592
cost-weighted distribution	
10^{th} percentile	0.496
25^{th} percentile	0.691
50^{th} percentile	1.043
75^{th} percentile	1.585
90^{th} percentile	1.940
misallocation losses, %	21.63

- As dispersed as De Loecker–Eeckhout–Unger, Baqaee–Farhi estimates
  - but they capture all distortions, not just menu costs

back

Why Menu Costs So Large?

- Continuous time, quadratic approximation, $\pi = 0$, $\rho \downarrow 0$

- Cost of price rigidity for firm value

$$C^V = -\underbrace{\frac{\sigma(\sigma-1)}{12\eta}}_{=\frac{6\times 5}{12\times 2/3}} \underbrace{\mathbb{E}[\Delta p^2]}_{=0.195^2} \underbrace{\left(\mathbb{K}[\Delta p] + \Psi([\mathbb{K}[\Delta p]])\right)}_{=3.649+1.25} \times 100; \;\; \Psi(1) = 1, \Psi(6) = 0$$

- Three components
  - strategic complementarities: $\frac{\sigma(\sigma-1)}{12\eta}$
  - misallocation: $\mathbb{E}[\Delta p^2]\mathbb{K}[\Delta p]$
  - size of menu cost: $\mathbb{E}[\Delta p^2]\Psi([\mathbb{K}[\Delta p]$

back

Importance of Extensive Margin

Inflation Volatility

	Data	Model
s.d. $\pi_t(s)$	2.87	2.87
s.d. $\pi_t^c(s)$	2.51	2.83
ratio	0.87	0.99

Slope of $\pi_t^c(s)$ on $\pi_t(s)$

	Data	Model
all observations	0.80	0.99
$\pi_t(s) > 75^{th}$ pct.	0.48	0.94
$\pi_t(s) > 90^{th}$ pct.	0.39	0.92

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Importance of Extensive Margin

Inflation Volatility

	Data	Our model
s.d. $\pi_t(s)$	2.87	2.87
s.d. $\pi_t^c(s)$	2.51	2.55
ratio	0.87	0.89

Slope of $\pi_t^c(s)$ on $\pi_t(s)$

	Data	Model
all observations	0.80	0.89
$\pi_t(s) > 75^{th}$ pct.	0.48	0.72
$\pi_t(s) > 90^{th}$ pct.	0.39	0.64

standard back

Markup Dispersion

- Our model: much less dispersion in markups, misallocation

	Our model	Standard
cost-weighted average	1.194	1.191
sales-weighted average	1.210	1.285
cost-weighted distribution		
10^{th} percentile	1.019	0.827
25^{th} percentile	1.088	0.918
50^{th} percentile	1.195	1.103
75^{th} percentile	1.266	1.405
90^{th} percentile	1.382	1.793
misallocation losses, %	1.97	21.24

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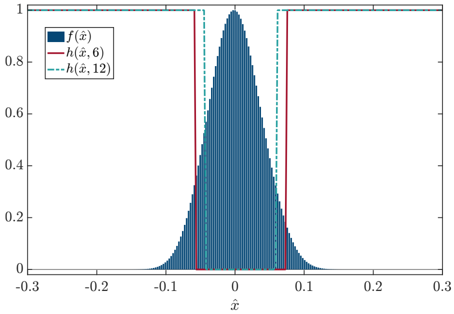
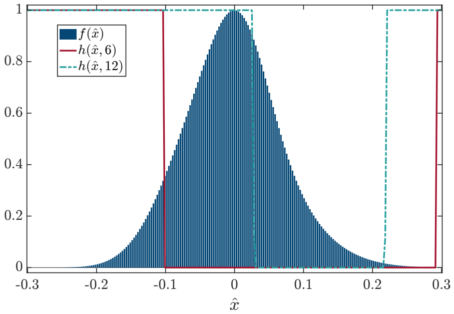
Distribution of Firm Price Gaps

Our Model



Standard



Narrower (s, S) bands, less dispersed price gap distribution in our model

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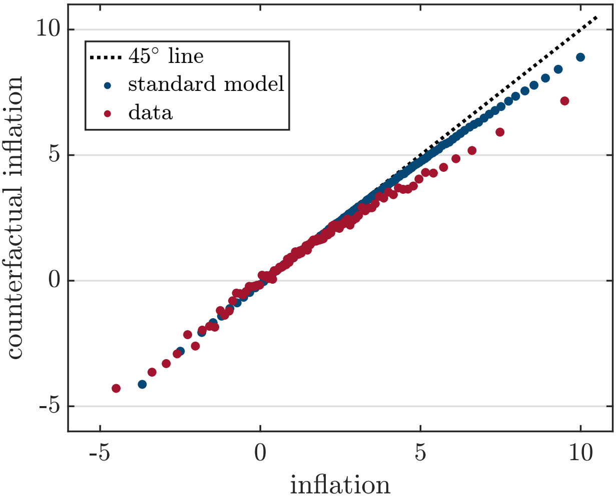
Extensive Margin: Standard Model



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Importance of Extensive Margin

Inflation Volatility

	Data	Our model	Standard
s.d. $\pi_t(s)$	2.87	2.87	2.86
s.d. $\pi_t^c(s)$	2.51	2.55	2.70
ratio	0.87	0.89	0.94

Elasticity of $\pi_t^c(s)$ to $\pi_t(s)$

	Data	Our Model	Standard
all observations	0.80	0.89	0.94
$\pi_t(s) > 75^{th}$ pct.	0.48	0.72	0.82
$\pi_t(s) > 90^{th}$ pct.	0.39	0.64	0.78

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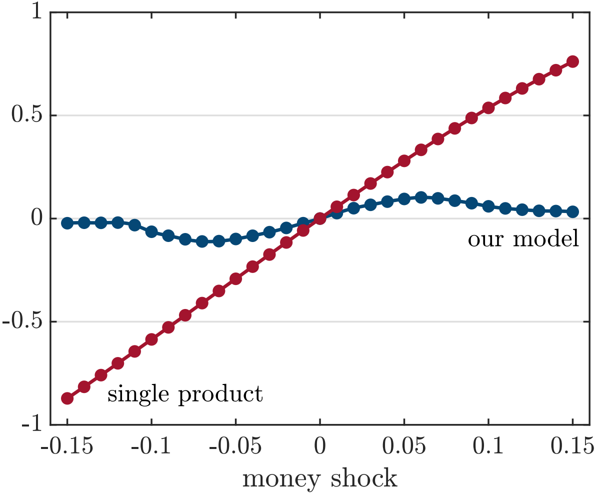
Cumulative Impulse Response



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Inflation Pass-through to Monetary Shock Δm

- Absent shock, inflation equal to

$$\pi = \int \omega h(\omega)\, \mathrm{d}f(\omega)$$

  - ω: desired price change, $h(\omega)$: adjustment hazard, $f(\omega)$: distribution

- Shock changes inflation to

$$\tilde{\pi} = \int (\omega + \alpha)\, \tilde{h}(\omega)\, \mathrm{d}f(\omega)$$

  - $\alpha = \tilde{x}^* - x^* + \Delta m$: response of reset price to shock
  - $\tilde{h}(\omega)$: adjustment hazard after shock

- Caballero-Engel 2007 decomposition

$$\Delta\pi = \underbrace{\alpha \int h(\omega)\, \mathrm{d}f(\omega)}_{\text{Calvo}} + \underbrace{\alpha \int \left(\tilde{h}(\omega) - h(\omega)\right) \mathrm{d}f(\omega)}_{\text{frequency}} + \underbrace{\int \omega \left(\tilde{h}(\omega) - h(\omega)\right) \mathrm{d}f(\omega)}_{\text{selection}}$$

Decompose Inflation Pass-through $\Delta\pi/\Delta m$

	Single-product			Our model		
	1%	5%	10%	1%	5%	10%
total pass-through	0.129	0.135	0.146	0.323	0.421	0.861
Calvo	0.094	0.096	0.098	0.095	0.099	0.111
frequency	0.001	0.004	0.011	0.009	0.123	0.660
selection	0.035	0.036	0.037	0.219	0.198	0.090

- Our model: larger, more non-linear inflation response
  - stronger selection effect for small shocks
  - stronger frequency response for large shocks

Economy Without Within-Firm Misallocation

- Set $\gamma = 0$ so no firm misallocation, $\phi_t(f,s) = \exp\left(-d_t(f,s)\gamma\frac{\sigma_z^2}{2}\right) = 1$

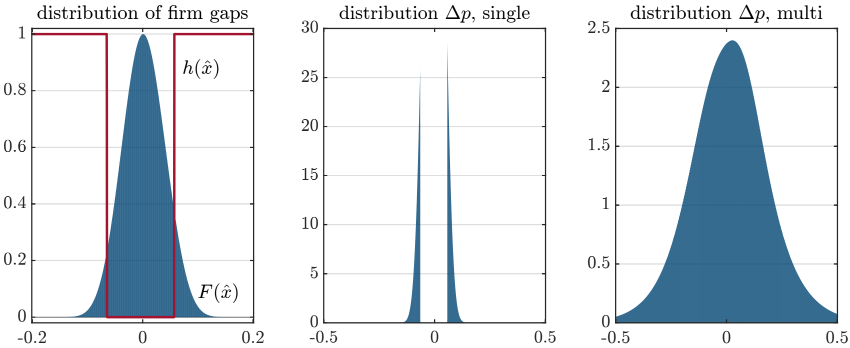
- Problem of multi-product firm identical to single-product firm ($\sigma_z = 0$)

- Provided adjust trend money growth g_m so same drift in

$$\hat{x}' = \exp\left((1-\gamma)\,\frac{\sigma_z^2}{2} + \sigma_u \varepsilon_{t+1}^u\,(f,s) - g_m\right)\hat{x}$$

- Calibrate multi-product economy, compare to equivalent single-product

Distribution of Price Changes



- Unlike single-product, multi-product economy matches distribution Δp
- But output responses identical to single-product economy
- Single-product model has strong selection effect (Golosov-Lucas, 2007)

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Robustness

- Single-product model without strategic complementarities, $\eta = 1$
- Multi-product model with $\gamma = 0$ and $\gamma = 3$
- Recalibrate to match same set of micro price statistics

	Single-product	Multi-product	
	$\eta = 1$	$\gamma = 0$	$\gamma = 3$
menu costs/sales	0.021	0.014	0.047
misallocation, %	5.71	0.92	3.97
slope of π_t^c on π_t			
all observations	0.99	0.88	0.89
$\pi_t > 90^{th}$ pct.	0.93	0.61	0.63

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