Menu Costs, Aggregate Fluctuations, and Large Shocks

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Motivation

- 5*pp* VAT increase/decrease in Hungary in 2006
- Reaction of prices Asymmetry
  - Flexible,
  - Asymmetric
- Menu costs and trend inflation
  - Works qualitatively (Ball-Mankiw, 1994)
  - Does it work quantitatively?

What we do?

- New-Keynesian heterogeneous-agent framework
  - Price-setting firms
  - Product-level and aggregate shocks
  - Trend inflation
  - Menu costs
- Our focus: product-level shock distribution
  - General parametric distribution: mixture of two Gaussians
  - Gaussian and Poisson (Gaussian with a Poisson arrival): special cases
- Exercise
  - Calibrate parameters to match price change distribution
  - Check responses to large aggregate tax shocks
  - Analyze predictions for small monetary shocks

Why we do it?

- Distribution of product-level shock determines monetary non-neutrality
  - Gaussian shocks: near neutrality (Golosov-Lucas, 2007)
  - Poisson shocks: non-neutrality (Midrigan, 2011)

- Why? Self-selection (Caplin-Spulber, 1987)
  - Who adjusts after an aggregate shock
  - High self-selection with Gaussian shocks:
    - Those with high desired price changes adjust (non-random)
  - Low self-selection with Poisson (like in Calvo, 1983):
    - Whoever gets an idiosyncratic shock, adjusts (near random)

- Responses to large shocks informative about distribution
  - The underlying price-gap distribution reveals itself,
  - Frequency depends on menu cost,
  - Both depend on the distribution

Preview of results

- Preferred distribution close to Poisson SS
- Captures frequency and asymmetric reactions to VAT shocks Shock
- Predicts near money neutrality and high selection IRF
  - Unlike Poisson

Flexible, asymmetric reactions to large shocks

- 5*pp* VAT increase/decrease in Hungary in 2006
  - Gross prices are quoted
  - Government sequentially closed the gap between tax rates
  - Preannounced, widely publicized
  - Easily identifiable aggregate cost shock
- Use micro-level pricing data (equivalent to Bils-Klenow, 2004)
  - Processed food sector (16% of CPI, homogeneous) 2009 July
  - 128 5-digit products (ELI), each in average 123 stores
  - Sales filtered
  - Moments calculated at product level, aggregated with expenditure weights

Flexible, asymmetric reactions to large shocks, cont.

- Moments

	Steady State		Tax changes	
	Baseline	Midr. (2011)	+5%	-5%
Frequency	12.6%	11.6%	62%	27%
Size	9.9%	11%	9%	8.6%
Kurtosis	4.0	4.0	8.1	9.2
Interquartile range	8.1%	8%	5.9	5.0
Inflation	4.2%	0%	55%	-12%

- VAT changes: Flexibility
  - +5% VAT: monthly frequency from 12.6% to 62%
- VAT changes: Asymmetry
  - −5% VAT: frequency to 26% vs. 62%

Implications

- Menu cost:
  - Not all affected firms responded
  - Despite preannounced, widely publicized shock
  - Asymmetry with trend inflation (Ball-Mankiw, 1994)

- Large shock: can help us learn about the underlying shock distribution

- Essential for monetary non-neutrality

Impact on non-neutrality: Inspecting the mechanism

- Continuum of firms ($i \in [0, 1]$)
- Discrete time $t = 0, 1, \ldots,$ with two subperiods
  - Day: menu cost ϕ^2 to adjust price P_{it}
  - Night: frictionless price change
- Firms' profit function: x_{it}^2, where ($x_{it} = \log P_{it} - \log P_{it}^*$)
- Ss band: probability of adjustment:

$$\Lambda(x_i) = \begin{cases} 0 & \text{if } |x_i| \leq \phi \\ 1 & \text{otherwise} \end{cases}$$

Inspecting the mechanism - A simple Ss model

- Permanent idiosyncratic and aggregate shocks (Δm_t)
- Price gap (x_i) distribution: Laplace (double exponential) with stochastic volatility

$$x_i \sim L(-\Delta m_t, \eta_{it}^2), \quad \eta_{it}^2 = \begin{cases} \lambda^2\sigma^2 & \text{with probability } p \\ \sigma^2 & \text{with probability } 1-p \end{cases}$$

Calibration

- The framework has 4 parameters
  - Menu cost ϕ^2
  - Probability of lower volatility p
  - High volatility σ^2
  - Volatility ratio λ^2
- How varying the volatility ratio (λ) influences non-neutrality?
  - $\lambda = 1$ no stochastic volatility (Laplace)
  - $\lambda = 0$ most stochastic volatility (Poisson-Laplace)

Calibration, cont.

- Price change distribution: $l(x_i)\Lambda(x_i)$
  - $l(x_i)$ is price-gap density
  - Moments in closed form
- We target 3 moments for each λ Parameters
  - Frequency of price changes (12.6%)
  - Size of absolute price changes (9.9%)
  - Kurtosis of price changes (4)

Selection

- $\Delta P = \int -x_i \Lambda(x_i) l(x_i) dx_i$

- Price level impact of a marginal shock (Caballero-Engel, 2007)

$$\left.\frac{\Delta P}{\Delta m}\right|_{\Delta m \to 0} = \underbrace{2 \int \Lambda(x_i) l(x_i) dx_i}_{\text{intensive}} + \underbrace{2\phi l(\phi)}_{\text{selection}}$$

- Intensive margin: all adjusters change by more
  - Constant: equals frequency
  - Independent of λ

- Selection: response of new adjusters
  - Multiple of the inaction band width (2ϕ) and
  - the density at the thresholds ($l(\phi)$)

Selection, cont.

- Distribution influences both pdfs
  - Laplace: wide inaction band and high mass at thresholds
  - Poisson: narrow inaction band and low mass at thresholds
  - Mixed: reinforcing increase in both
- Impact of varying λ: Selection
  - Remember: frequency, size, kurtosis constant (comp. Alvarez, Bihan, Lippi, 2014)
  - Non-neutrality and selection varies widely
- Key: Identify λ Identification
  - Either unconditional cross section (IQR) or time-series moments (variance of dispersion)
  - Or moments conditional on large shocks (frequency)

GE macro model

- Representative household
- Heterogeneous firms
  - Menu costs of price changes: to match inaction
  - Idiosyncratic shocks: to match large size of price changes
  - Multi-product firms: to match small price changes
  - Novel mixed normal distribution: to match price change distribution
- Exogenous aggregate monetary policy and tax shocks
- No closed form solutions, solved numerically with global heterogeneous agent methods

Household

- Maximizes utility

$$\max_{\{C_t(i,g),L_t\}} E \sum_{t=0}^{\infty} \beta^t \left(\log C_t - \mu L_t\right),$$

- subject to

$$\int_i \sum_g P_t(i,g) C_t(i,g) + B_{t+1}/R_t = B_t + W_t L_t + \tilde{\Pi}_t + T_t,$$

- CES aggregator:

$$C_t = \left(\int C_t(i)^{\frac{\theta-1}{\theta}} di\right)^{\frac{\theta}{\theta-1}}$$

$$C_t(i) = \left(\tfrac{1}{G} \sum_{g=1}^{G} \left[A_t(i,g) C_t(i,g)\right]^{(\gamma-1)/\gamma}\right)^{\gamma/(\gamma-1)}$$

Household, cont.

- Price indices

$$P_t = \left(\int P_t(i)^{1-\theta} di\right)^{\frac{1}{1-\theta}}$$

$$P_t(i) = \left(\frac{1}{G}\sum_{g=1}^{G} \left[P_t(i,g)/A_t(i,g)\right]^{1-\gamma}\right)^{1/(1-\gamma)}$$

- Euler equation

$$\frac{1}{R_t} = \beta E_t \frac{P_t C_t}{P_{t+1} C_{t+1}}$$

- Product demand

$$C_t(i,g) = A_t(i,g)^{-1} \left(\frac{P_t(i,g)/A_t(i,g)}{P_t(i)}\right)^{-\gamma} \left(\frac{P_t(i)}{P_t}\right)^{-\theta} C_t$$

- Labor supply

$$\mu C_t = W_t / P_t$$

Firms

- Production function for firm i, product g:

$$Y_t(i,g) = L_t(i,g)/A_t(i,g),$$

- $\ln A_t(i,g) = \ln A_{t-1}(i,g) + \varepsilon_t(i,g)$ idiosyncratic shock, with stochastic volatility

$$\varepsilon_t(i,g) \sim N(0,\delta_t^2), \delta_t^2 = \begin{cases} \lambda^2\sigma^2 & \text{with probability } p \\ \sigma^2 & \text{with probability } 1-p \end{cases}$$

- Gaussian ($\lambda = 1$), Poisson ($\lambda = 0$) shocks are special cases
- Menu cost $\phi P_t(i) C_t(i)$ to change all prices

Firms, cont.

- Period profit

$$\tilde{\Pi}_t(i) = \sum_{g=1}^{G} \left[\frac{1}{1+\tau_t} P_t(i,g) Y_t(i,g) - W_t L_t(i,g) \right]$$

- Normalized profit (by $P_t Y_t$):

$$\bar{\Pi}_t(i) = \sum_{g=1}^{G} \left[\frac{1}{1+\tau_t} p_t(i,g)^{1-\gamma} - w_t p_t(i,g)^{-\gamma} \right] \left(\frac{1}{G} \sum_{g=1}^{G} p_t(i,g)^{1-\gamma} \right)^{(\gamma-\theta)/(1-\gamma)}$$

  - $p_t(i,g) = \frac{P_t(i,g)}{A_t(i,g) P_t}$ is quality adjusted relative price
  - $w_t = W_t / P_t$ is real wage

Firms' dynamic program

- Single idiosyncratic state

$$\mu_{t-1}(i,g) = \frac{P_{t-1}(i,g)}{A_t(i,g)P_{t-1}} = p_{t-1}(i,g)\frac{A_{t-1}}{A_t}$$

- Aggregate state variables $\Omega_t = \{\tau_{t+i}, M_{t+i}, \Gamma_{t+i}\}_{i=0}^{\infty}$

- Two options: change, don't change

- No price-change

$$V^{NC}\left(\mu_{t-1}(i), \Omega_t\right) = \bar{\Pi}\left(\frac{\mu_{t-1}(i)}{1+\pi_t}, w_t, \tau_t\right) + \beta E_t V\left(\frac{\mu_{t-1}(i)e^{\varepsilon_{t+1}(i)}}{1+\pi_t}, \Omega_{t+1}\right),$$

Firms' dynamic program, cont.

- Price change

$$V^C(\Omega_t) = \max_{\mathbf{p}_t^*(i)} \{\Pi(\mathbf{p}_t^*(i), w_t, \tau_t) - \phi + \beta E_t V\left(\mathbf{p}_t^*(i) e^{\varepsilon_{t+1}(i)}, \Omega_{t+1}\right)\}.$$

- Value function

$$V(\mu_{t-1}(i), \Omega_t) = \max_{\{C,NC\}} \left[V^{NC}(\mu_{t-1}(i), \Omega_t), V^C(\Omega_t)\right].$$

Monetary and fiscal policy

- Steady state (no aggregate uncertainty):
  - Constant money growth (g_M)
  - Constant VAT rate (τ)

- Aggregate shocks (perfect foresight transition)
  - Unexpected persistent money growth shock

$$\log(M_t/M_{t-1}) = g_{Mt} = \mu_M + \rho_M g_{Mt-1} + \varepsilon_{Mt}$$

  - Permanent, preannounced VAT shock

$$\tau_t = \tau_{t-1} + \varepsilon_{\tau t}$$

- Revenues are redistributed lump-sum

$$M_t - M_{t-1} + \frac{\tau_t}{1+\tau_t} P_t C_t = T_t$$

Equilibrium and solution

- Equilibrium
  1. Household maximizes utility subject to budget constraint taking prices, wages as given
  2. Firms set nominal prices to maximize their value functions, taking their relative prices and idiosyncratic technology, and the future path of aggregate variables as given.
  3. Money supply equals aggregate demand $M_t = P_t C_t$.
  4. Money supply growth, taxes follow exogenous path.
  5. Market clearing in the goods, bond, labor markets.

- Solution
  - Solved numerically with global heterogeneous agent methods Solution

Calibration

- Set some parameters exogenously
  - Correlation of idiosyncratic shocks within firms $\rho_\varepsilon = 0.6$
  - Discount rate: $\beta = 0.96$ yearly
  - Elasticity of substitutions: $\theta = 5, \gamma = 1.1$
  - Trend inflation: $\pi = 4.2\%$
- Calibrate Parameters
  - Menu cost ϕ
  - Idiosyncratic shock variance σ_ε
  - Probability of low variance p
  - Variance ratio λ

Calibration, cont

- Target Targeted Moments
  - frequency and average absolute size of price change
  - kurtosis of the size distribution
  - interquartile range of the absolute size distribution
- Model matches price change distribution SS

How our model does?

- Model matches moments after large shocks
  - Predicts inflation pass-through and asymmetry Inflation Pass-through
  - Predicts frequency and size Frequency Size
  - Predicts distribution Kurtosis IQR
- Model also predicts near money neutrality IRF
  - Why? Introducing realistic distribution increases selection

Robustness

- Robust real effects Robustness
  - Random menu cost ($\rho_{\varepsilon} = 0$)
  - Random menu cost recalibrated for 0 inflation
  - Single product version
  - Baseline version with 2% inflation Inflation
- 2009 July: 5% shock 2009 July
  - Conditional on lower pass-through; asymmetry is justified

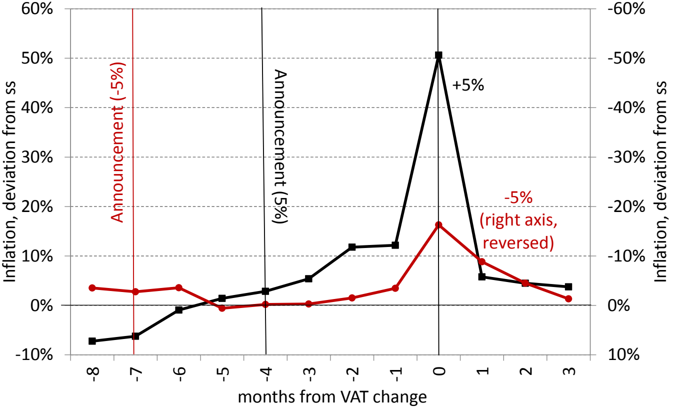
Related literature

- Monetary non-neutrality and selection: Caplin-Spulber (1987), Golosov-Lucas (2008), Gertler-Leahy (2008), Midrigan (2011), Vavra (2014), Alvarez, Bihan, Lippi (2014)
- Evidence supporting state-dependent pricing models: Gagnon (2009, et.al. 2012), Costain-Nakov, 2014 Alvarez et.al. (2012)
- Evidence supporting menu cost assumptions:
  - vs. information frictions: Mankiw-Reis (2002), Woodford (2003), Mackowiak-Wiederholt (2009)
  - vs. search frictions: Cabral-Fishman (2012), Yang-Ye (2008)
  - vs. fairness: Rotemberg (2005, 2011)

Conclusion

- Novel stylized fact
  - Large and asymmetric response to large aggregate shocks
- Menu cost model with mixed normal distribution and inflation matches pricing facts well
- Implies monetary near-neutrality
- Price-rigidity insufficient to explain macro-evidence on the real effects of monetary shocks
- Need other frictions: wage-rigidity, real rigidity, information frictions

Inflation responses to value-added tax changes



Hungary, 2006, Processed food

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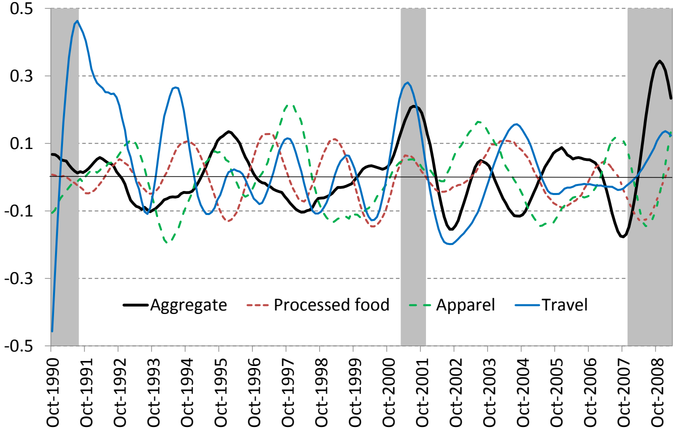
Cyclical variation in dispersion across sectors



source: Vavra (2014), US CPI, band-pass filtered

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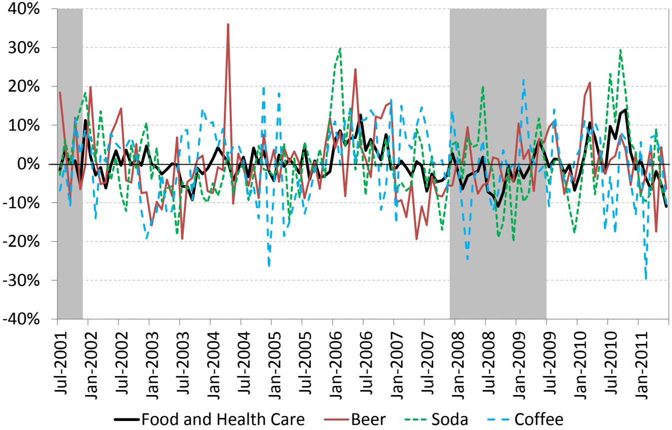
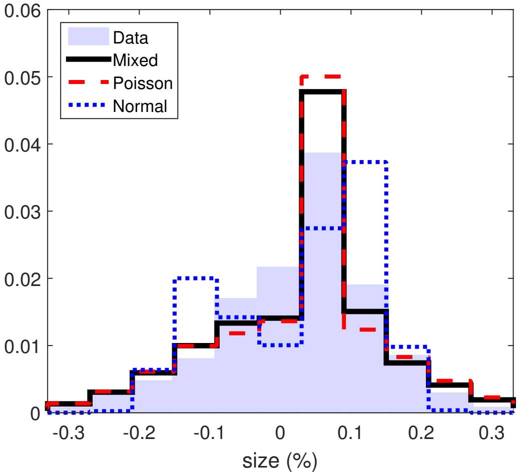
Cyclical variation in dispersion across goods



source: IRI dataset, NY-SF-Ch, Hodrick-Prescott filtered

Steady state distribution of price changes



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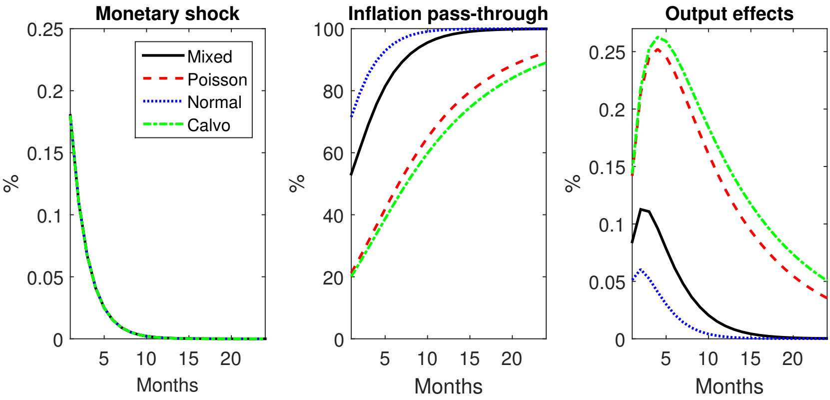
Impulse responses to a monetary shock



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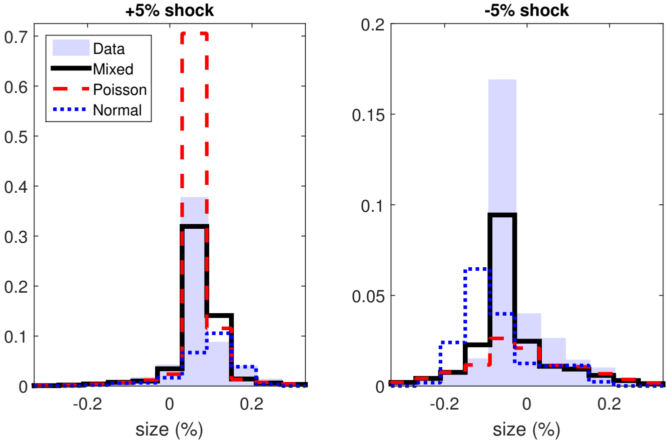
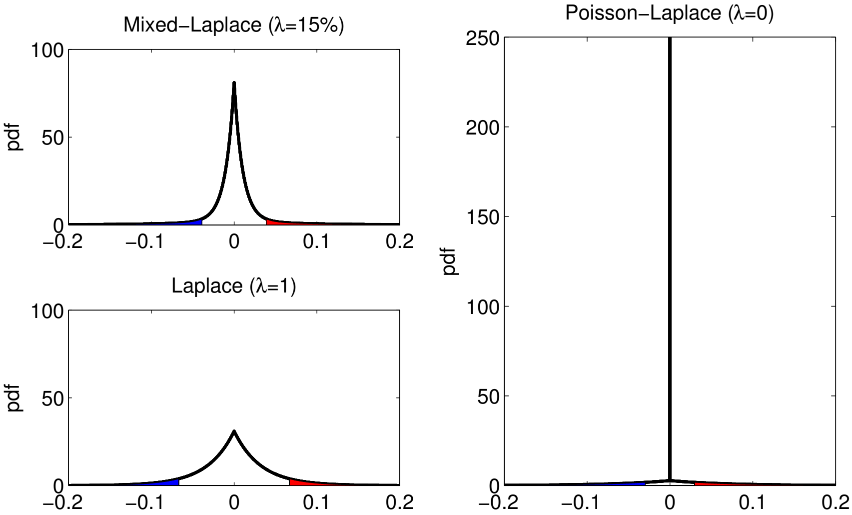
Price changes at the months of tax changes



Price-gap and price change distributions



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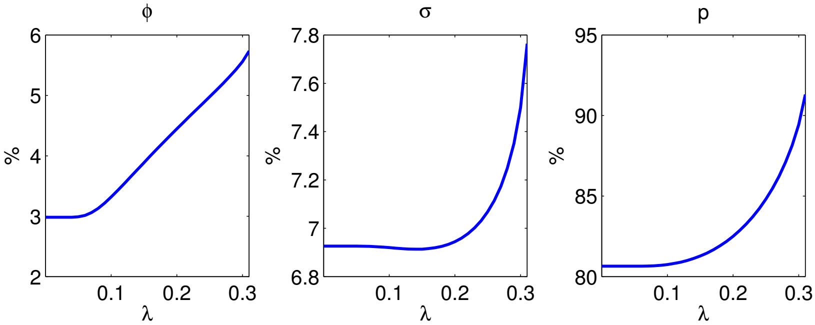
Calibrated parameters



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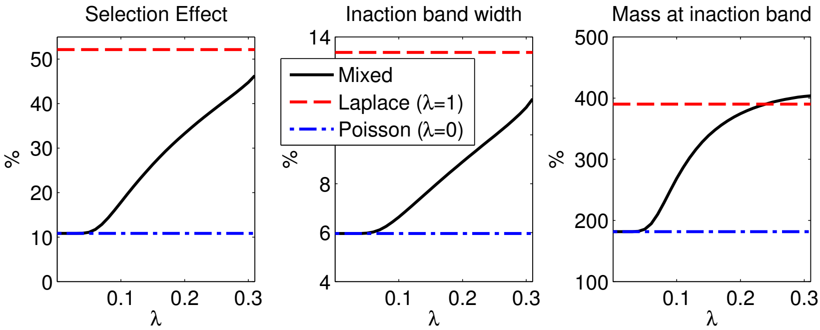
Selection and determinants



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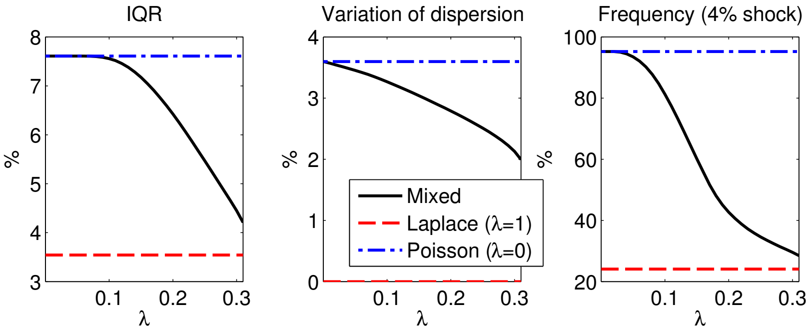
Identification of the volatility ratio



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Calibrated parameters

Parameters	**Mixed**	**Poisson**	**Normal**
ϕ	2.4%	1.6%	5.0%
σ_A	4.3%	4.4%	3.8%
p	91.2%	90.6%	0
λ	8.8%	0	1

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Matched moments

Used in calibration	Data		Models		
	Baseline	Midr. (2011)	Mixed	Poisson	Normal
Frequency	12.6%	11.6%	12.6%	12.6%	12.6%
Size	9.9%	11%	9.9%	9.9%	9.9%
Kurtosis	3.98	4.02	3.98	3.98	*1.97*
Interquartile range	8.13%	8%	8.13%	*9.55%*	*6.3%*
Inflation	4.23%	0%	4.23%	4.23%	4.23%

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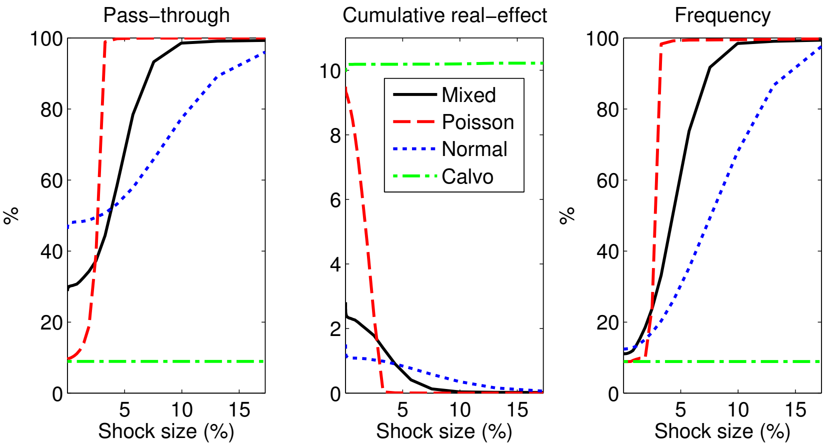
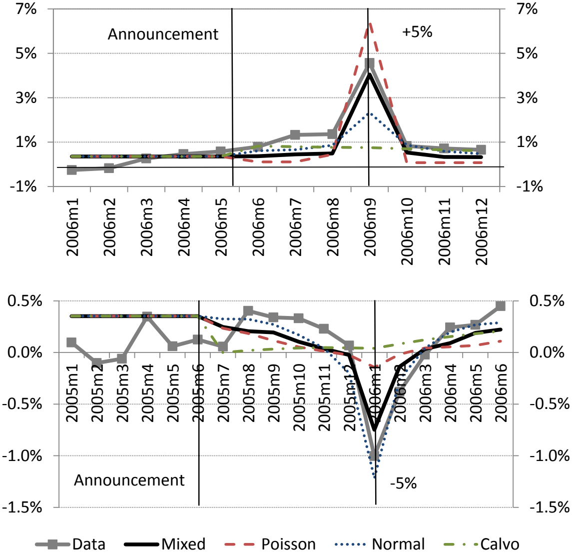
Simulated effects of large shocks



Monthly inflation



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Pass-through

Moment	Size	**Data**	**Mixed**	**Poisson**	**Normal**	**Calvo**
Pass through	+5%	99%	88%	143%	49%	8.0%
	-5%	33%	27%	12%	39%	6.6%

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Frequency

Moment	Size	**Data**	**Mixed**	**Poisson**	**Normal**	**Calvo**
Frequency	+5%	62%	55%	90%	25%	12.6%
	-5%	27%	19%	11%	17%	12.6%

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Size

Moment	Size	**Data**	**Mixed**	**Poisson**	**Normal**	**Calvo**
Frequency	+5%	9.0%	8.4%	7.5%	10.2%	
	-5%	8.6%	8.5%	10.4%	10.7%	

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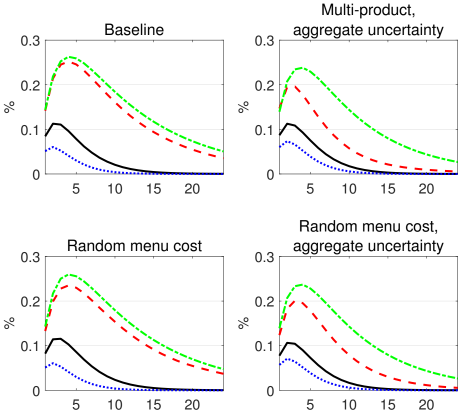
Kurtosis

Moment	Size	**Data**	**Mixed**	**Poisson**	**Normal**
Kurtosis	+5%	8.1	13.1	21.3	5.6
	-5%	9.2	5.9	3.4	3.4

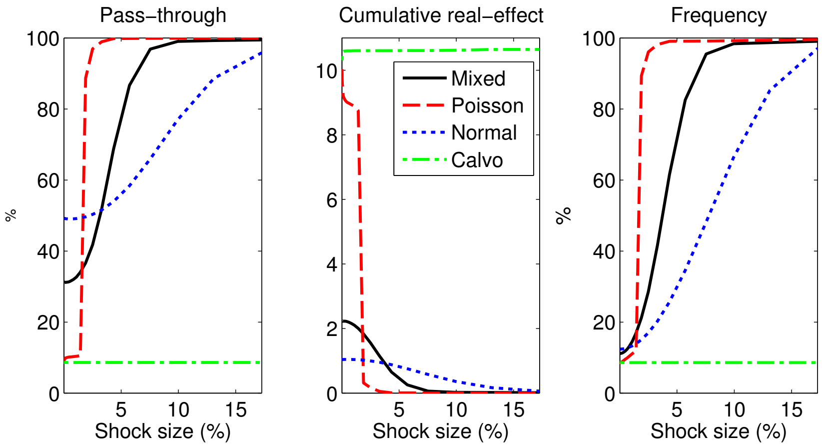
Interquartile range

Moment	Size	**Data**	**Mixed**	**Poisson**	**Normal**
Interquartile range	+5%	5.9	4.3	2.7	6.5
	-5%	5.0	5.8	11.5	6.6

Real effects in various versions



Large shocks in the single product version



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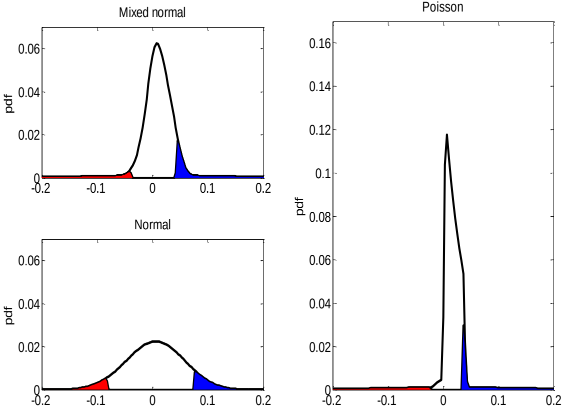
Positive trend inflation



Pass-through	**Dec06-Inc09**	**Inc06-Inc09**
# of products	29	73
Inflation	4.7%	4.7%
Frequency	12.9%	12.4%
2006 January, -5%	31.3%	
2006 September, +5%		88%
2009 July +5%	68.8%	51.1%

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Numerical solution: Steady state

- No aggregate uncertainty
- Aggregate endogenous variables are constant
  - inflation: $\pi_t = \pi = \mu_M/(1-\rho_M)$, real wage: w_t constant
  - distribution over idiosyncratic state variables Γ is time-invariant

- Iteration in w
  1. Guess a value w_0 (implies an aggregate supply Y)
  2. For $w_i = w_{i-1}$ solve for value and policy functions
  3. Calculate equilibrium quality-adjusted relative price distribution (Γ_i)
  4. Calculate aggregate demand (C_t)
  5. If excess demand, increase w_{i+1}; repeat until convergence

Numerical solution: Transitional dynamics

- One time persistent/permanent shock to g_M, τ
  - Shooting
  - Assume new SS reached in T periods
  - Iterate on inflation path
    1. Guess inflation path $\{\pi_1, \pi_2, ..., \pi_T\}$
    2. Money growth implies an output growth and real wage $\{w_t\}$ path
    3. Calculate value- and policy functions by backward induction
    4. Calculate price distribution path
    5. Obtain resulting inflation path
    6. Do until convergence in inflation paths

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