# Logit price dynamics

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# Three approaches to price stickiness

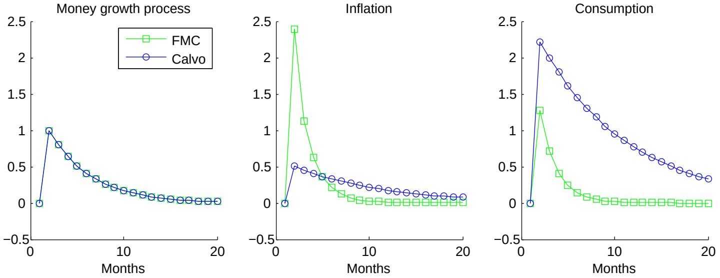
1. **Arbitrary failures to adjust:**
   - Taylor (1979), Calvo (1983)
2. **"Menu costs":**
   - Barro (1972), Mankiw (1985), Caplin-Spulber (1987)
   - Dotsey et al (1999), Golosov-Lucas (2007), Midrigan (2011)
3. **Costly or imperfect information processing and decisions**, including:
   - Akerlof-Yellen (1985), Mankiw-Reis (2002)
   - Sims (2003), Woodford (2009)

- Case study evidence of Zbaracki et al (2004) points to **managerial costs**

# Some facts on retail price adjustment

- **Small and large** price changes coexist (Klenow-Malin "Fact 7")
  - Histogram in model of **fixed menu costs** has only **two sharp spikes**
- Adjustment **hazard decreases weakly** over time (K-M "Fact 10")
  - Model of **fixed menu costs** implies increasing hazard
- Expected **size of adjustment** ≈ constant over time (K-M "Fact 10")
  - **Calvo model** implies size of adjustment increases with time
- **Extreme prices** are typically young (Campbell-Eden 2010)
- **Prices are more volatile** than costs (Eichenbaum *et al* 2011)
  - **Calvo or fixed menu cost model with autoregressive productivity** implies prices are less volatile than costs

# Getting the right model matters!



# Our paper: costly decisions

1. **Main assumption: precise decisions are costly.**
   Making exactly the right decision at all points in time is extremely (infinitely!) costly.

2. Game theoretic approach: **“control costs”**.
   1. Assume a **cost function** for **precision**.
   2. Implies **mistakes** occur in equilibrium.
   3. If precision is measured by **entropy**, then choices distributed as **logit** (Mattsson and Weibull, 2002).

3. Two margins for errors:
   1. **When** to adjust price (like Costain-Nakov JME 2011)
   2. **Which price** to set (like Costain-Nakov ECB WP 1375)

4. This paper shows how the two margins interact.

# Possible interpretations

1. Putting **"logit equilibrium"** or **"control costs"** in a macro model
   - Showing how to apply "control costs" to decision of **when** to adjust
2. Replacing **"menu costs"** with **costs of managerial decisions**
3. Showing that **near-rational** price adjustment, where errors can occur if they are not too costly, is **tractable and empirically successful**
4. Focusing on **cost of choice** rather than **cost of information** makes our setup "infinitely" easier to solve than "rational inattention" of Sims (2003)

# Recent related papers

- **Empirics of price adjustment**
  - Klenow-Kryvtsov (2008); Nakamura-Steinsson (2008); Klenow-Malin (2010)
  - Document stylized facts about micro price adjustment by retailers
- **Menu cost models**
  - Golosov-Lucas (2007); Midrigan (2011); Dotsey-King-Wolman (2013); Alvarez-Gonzalez-Neumeyer-Beraja (2011)
  - Feature aggregate and idiosyncratic shocks; fit to micro data and study macro implications
  - In our model, there is no menu cost but instead a “control cost”

# Recent related papers

- **Menu costs vs. observation costs**
  - Mankiw-Reis (2002); Reis (2006)
  - Pay a small cost to get full information
  - Alvarez-Lippi-Paciello (2011)
  - Includes both menu costs and observation costs
  - Just two free parameters but empirically successful
  - But they don't calculate general equilibrium impulse responses
- **Rational inattention**
  - Sims (2003); Woodford (2009); Matejka (2011)
  - Constraint on flow of information from environment to decision-maker
  - Our model instead has full information, yet decisions are subject to error because of control costs

# Summary of results

1. Model **nominal rigidity** based on **costly decision making**
   - Costs $\propto$ entropy $\rightarrow$ decisions are logit
2. Show how to model **costly decisions of timing**
   - Two parameters required, measuring **speed** and **accuracy** of decisions
3. Microeconomic results (errors in choosing **which price** are helpful):
   - Large and small price adjustments coexist
   - Adjustment hazard is largely independent of age of price
   - Adjustment size is largely independent of age of price
   - Extreme prices are younger
   - Prices more volatile than costs
4. Macroeconomic results (errors in **when to adjust** are helpful):
   - Substantial nonneutrality, midway between Calvo and menu costs
5. Like Sims (2003), Woodford (2009), but numerically feasible

# CONTROL COSTS AND LOGIT

# Decision environment: intermittent adjustment

- Consider a decision-maker who **intermittently adjusts** a number $p$
- Payoffs depend on $p$, and on exogenous shocks
- **Current $p$ remains in effect** until decision-maker sets a new $p'$
- There are no other control variables.

- We model this environment, assuming that **decisions are costly**.

# Deriving multinomial logit from control costs

- Think of **decisions** as **probability distributions** over alternatives.
- Suppose the **time cost** of decision $\pi$ is:

$$\kappa \mathcal{D}(\pi|u) \equiv \kappa \sum_{j=1}^{n} \pi^j \log\left(\frac{\pi^j}{n^{-1}}\right) = \kappa\left(\log(n) + \sum_{j=1}^{n} \pi^j \log \pi^j\right)$$

  - This is the **relative entropy** of decision $\pi$, compared with perfectly uniform decision $u$.
  - Also called Kullback-Leibler divergence.
  - It means choice is more costly if more precise.
  - Normalizes cost of uniform decision to zero.
  - **Marginal** cost of perfect decision is infinite.

# Deriving multinomial logit from control costs

- Maximize expected value minus expected costs:

$$\tilde{V} = \max_{\pi^j} \sum_j \pi^j V^j - \kappa W \left( \log(\#p) + \sum_j \pi^j \log \pi^j \right) \text{ s.t. } \sum_j \pi^j = 1$$

  - $V^j$ is nominal value of alternative $j$
  - $W$ is nominal value of time

- First-order condition:

$$V^j - \kappa W(1 + \log \pi^j) = \mu$$

- Rearranging, obtain

$$\pi^j = \frac{\exp(V^j/(\kappa W))}{\sum_k \exp(V^k/(\kappa W))}$$

# Some technicalities

- Plug $\pi^j$ into the objective to **calculate the value function**:

$$\tilde{V} \;=\; \kappa W \log\left(\frac{1}{\#p}\sum_j \exp\left(\frac{V^j}{\kappa W}\right)\right).$$

  - "Cumulant generating function"

- Considering a **finer grid is irrelevant** ...
  - ... because of **relative** entropy.
- Considering a **different functional form is irelevant**...
  - ... because decisions are always strongly centered around the optimum.

- But considering a **wider grid does matter** ...
  - ... because **"irrelevant alternatives"** may be **relevant** to error-prone decision-makers.

# Deriving logit timing from control costs

- Suppose **time cost** of the adjustment hazard $\lambda$ is:

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

  - This is the **relative entropy** of endogenous adjustment hazard $\lambda$, compared with exogenous adjustment hazard $\bar{\lambda}$.
  - It means costs are greater if adjustment probability varies over time.
  - Normalizes cost of *some Calvo model* to zero.

# Deriving logit timing from control costs

- Maximize expected gains minus expected costs

$$G_t \;=\; \max_{\lambda} \lambda D_t - \kappa W_t \left( \lambda \log \frac{\lambda}{\bar{\lambda}} + (1-\lambda) \log \frac{1-\lambda}{1-\bar{\lambda}} \right)$$

  - $D_t$ is value of adjustment at $t$
  - $W_t$ is value of time at $t$
- First-order condition:

$$D_t = \kappa W_t \left( 1 + \log \frac{\lambda}{\bar{\lambda}} - \left( 1 + \log \frac{1-\lambda}{1-\bar{\lambda}} \right) \right)$$

- Rearranging,

$$\lambda_t \;=\; \frac{\bar{\lambda}}{\bar{\lambda} + (1-\bar{\lambda}) \exp\left(-D_t/(\kappa W_t)\right)} \tag{1}$$

- Same as Woodford (2009)

# Some technicalities

- Plug $\lambda_t$ into the objective to **calculate the value function**:

$$G_t \;=\; \kappa W_t \log\left(1-\bar{\lambda}+\bar{\lambda}\exp\left(\frac{D_t}{\kappa W_t}\right)\right).$$

- Two free parameters: **noise** $\kappa$ and **rate** $\bar{\lambda}$
- Interpretation of $\bar{\lambda}$: Adjustment probability when indifferent.

# Some technicalities

**Naive alternative setup.**

- Choose "adjust" (value $\tilde{V}_t$) or "not" (value $V_t$).
- Cost function:

$$\kappa\mathcal{D}(\{\lambda, 1-\lambda\}||\{0.5, 0.5\}) = \kappa\left(\log(2) + \lambda\log\lambda + (1-\lambda)\log(1-\lambda)\right)$$

- Implied hazard:

$$\lambda_t = \frac{\exp(\tilde{V}_t/(\kappa W_t))}{\exp(\tilde{V}_t/(\kappa W_t)) + \exp(V_t/(\kappa W_t))}$$

- What's the problem?
  - Adjust with probability 0.5 per period when indifferent, **regardless of period length**!!
  - Not well behaved as time period $\to 0$.
  - **Rate parameter needed!!**

# MODEL

# Model: monopolistic firms

- Firm's demand: $Y_{it} = \theta_t P_{it}^{-\epsilon}$
- Firm's output: $Y_{it} = A_{it} N_{it}$
- Idiosyncratic productivity: $\log A_{it} = \rho \log A_{it-1} + \varepsilon_{it}^{a}$
- Profits: $U_{it} = P_{it} Y_{it} - W_t N_{it} = U_t(P_{it}, A_{it})$
- Frictionless optimal choice would imply:

$$V_t^*(A_{it}) = \max_P U_t(P, A_{it}) + E[Q_{t,t+1} V_{t+1}^*(A_{it+1})]$$

... but now there are mistakes and control costs.

# Model: mistakes in price choice

- Instead of *optimal* price $P_t^*(A_{it})$...
- ... there is a **logit distribution** across possible prices:

$$\pi_t(P|A_{it}) = \frac{\exp(\kappa^{-1} W_t^{-1} V_t(P, A_{it}))}{\sum_{P'} \exp(\kappa^{-1} W_t^{-1} V_t(P', A_{it}))}$$

- The **value of adjusting** is:

$$\begin{aligned} \tilde{V}_t(A_{it}) &= \sum_P \pi_t(P|A_{it}) V_t(P, A_{it}) - W_t K_t^\pi \\ &= E^\pi V(P, A_{it}) - W_t K_t^\pi \end{aligned}$$

- ... which includes the adjustment cost:

$$W_t K_t^\pi = W_t \kappa \mathcal{D}(\pi_t | u)$$

# Model: mistakes in timing

- Optimal timing is to adjust iff $E^{\pi} V_t(P, A_{it}) - W_t K_t^{\pi} > V_t(P_{it}, A_{it})$.
- But here, instead, adjustment hazard is a **weighted logit**:

$$\lambda(L) = \frac{\bar{\lambda}}{\bar{\lambda} + (1 - \bar{\lambda}) \exp(-L)},$$

- ... where $L$ is **real loss from not adjusting:**

$$L = L_t(P_{it}, A_{it}) = \frac{E^{\pi} V_t(P, A_{it}) - W_t K_t^{\pi} - V_t(P_{it}, A_{it})}{\kappa W_t}$$

  - Noise parameter $\kappa \in [0, \infty)$ controls precision of timing.

- Each period, pay a cost to check whether it is a good time to adjust:

$$W_t K_t^{\lambda} = W_t \kappa \mathcal{D} \left( \{\lambda(L), 1 - \lambda(L)\} || \{\bar{\lambda}, 1 - \bar{\lambda}\} \right)$$

# Bellman equation

- **Value of production now** at current firm-specific state $(P, A)$:

$$
\begin{aligned}
V_t(P,A) &= U_t(P,A) \\
&+ E_t \left\{ Q_{t,t+1} \max_{\lambda} \left[ (1-\lambda) V_{t+1}(P,A') + \lambda \tilde{V}_{t+1}(A') \right. \right. \\
&- \left. \left. W_{t+1} \kappa \mathcal{D}\{(\lambda, 1-\lambda) || (\bar{\lambda}, 1-\bar{\lambda})\} \right] \Big| A \right\}
\end{aligned}
$$

  - Here $V_{t+1}(P, A')$ = value of continuing next period without adjusting
  - And $\tilde{V}_{t+1}(P, A')$ = expected value of continuing after adjustment:

$$
\begin{aligned}
\tilde{V}_{t+1}(A') &= \max_{\pi^j} \sum_j \pi^j V_{t+1}(P^j, A') - W_{t+1} \kappa \mathcal{D}(\pi || u) \\
& \text{s.t.} \quad \sum_j \pi^j = 1
\end{aligned}
$$

# Bellman equation (collecting terms)

- **Value of production now** at current firm-specific state $(P, A)$:

$$V_t(P,A) = U_t(P,A) + E_t\left\{Q_{t,t+1}\left[V_{t+1}(P,A') + G_{t+1}(P,A')\right]|A\right\}$$

  - Here $V_{t+1}(P,A')$ = value of continuing next period without adjusting
  - And $G_{t+1}(P,A')$ = expected gains from price adjustment next period:

$$\begin{aligned} G_t(P,A) &= \kappa W_t \log\left(1-\bar{\lambda}+\bar{\lambda}\exp\left(\frac{D_t(P,A)}{\kappa W_t}\right)\right) \\ D_t(P,A) &= \kappa W_t \log\left(\frac{1}{\#p}\sum_j \exp\left(\frac{V_t(P^j,A)}{\kappa W_t}\right)\right) - V_t(P,A) \end{aligned}$$

# Versions compared

Actually, we will compare six versions of the model:

- **"Precautionary price stickiness"**: errors in price choice. Timing optimal.
  - PPS-logit
  - PPS-control
- **"Woodford"**: errors in timing. Set optimal price when adjustment occurs.
  - Woodford-logit
  - Woodford-control
- **"Nested"**: errors in price choice and timing.
  - Nested-logit
  - Nested-control

- Some versions just impose **logit**, without subtracting control costs
- Other versions derive logit from **control costs**

# Model: the rest is standard

- Household utility: $\frac{C^{1-\gamma}}{1-\gamma} - \chi N + \nu \log(M/P)$ with discount $\beta$
- Period budget constraint:

$$P_t C_t + M_t + R_t^{-1} B_t = W_t N_t + M_{t-1} + T_t + B_{t-1} + \Pi_t$$

- Consumption bundle:

$$C_t = \left[ \int_0^1 C_{it}^{\frac{\epsilon-1}{\epsilon}} di \right]^{\frac{\epsilon}{\epsilon-1}} \text{ with price } P_t \equiv \left[ \int_0^1 P_{it}^{1-\epsilon} di \right]^{\frac{1}{1-\epsilon}}$$

- Money supply: $M_t = \mu \exp(z_t) M_{t-1}$, where $z_t = \phi_z z_{t-1} + \epsilon_t^z$
  - ... will also consider Taylor rule ....

# Model: aggregate consistency and aggregate state variable

- Labor market clearing: $N_t = \Delta_t C_t$
- Measure of price dispersion: $\Delta_t \equiv P_t^{\epsilon} \int_0^1 P_{it}^{-\epsilon} A_{it}^{-1} di$
- Balanced budget: $M_t = M_{t-1} + T_t$
- Bond market clears: $B_t = 0$
- Aggregate state variable: $\Omega_t \equiv (z_t, M_{t-1}, \mathbf{\Psi_{t-1}})$ ...
  - ... where $\mathbf{\Psi_{t-1}}$ is the cross-sectional distribution of prices and productivities at time $t-1$

# COMPUTATION

# Computation

- Challenge: need to keep track of the *distribution* of firms
- Reiter's (2009) method of "projection & perturbation"
- Appropriate for price-setting by firms: idiosyncratic shocks are relatively large; aggregate shocks are relatively small
- Two-step procedure, computing:
  1. Aggregate steady-state by backwards induction on a finite grid
  2. Aggregate dynamics by linearization around each grid point

# Finite grid approximation

- To keep track of value function and cross-sectional distribution, define them over finite grid.

- Grid of real firm-specific states: $\Gamma = \Gamma^a \times \Gamma^p$ ...
  - ... where $\Gamma^a \equiv \{a^1, a^2, ...a^{\#a}\}$, $\Gamma^p \equiv \{p^1, p^2, ...p^{\#p}\}$

- Exogenous Markov matrix describes productivity:

$$\mathbf{S}: \quad s^{jk} = prob(a^j | a^k)$$

- Endogenous, time-varying Markov matrix deflates real prices:

$$\mathbf{R}_t: \quad r^{jk} = prob(p^j | p^k, P_t / P_{t-1})$$

  - (If previous real price was $p^k$, $\mathbf{R}_t$ only allocates positive probability to the two grid points bounding $\frac{P_{t-1}}{P_t} p^k$.)

# Computation: aggregate steady-state (projection)

Real prices converge to an ergodic distribution $\boldsymbol{\Psi}$.

1. Guess real wage: $w$
2. Consumption: $C = (\chi/w)^{1/\gamma}$
3. Payoff at grid points: $U^{jk} = \left(p^j - w/a^k\right) C(p^j)^{-\epsilon}$
4. Iterate on Bellman equation: $\mathbf{V} = \mathbf{U} + \beta \mathbf{R}' \left(\mathbf{V} + \mathbf{G}\right) \mathbf{S}$
5. Iterate on distribution matrices:
   - Beginning of period: $\tilde{\boldsymbol{\Psi}} = \mathbf{R} \boldsymbol{\Psi} \mathbf{S}'$
   - End of period: $\boldsymbol{\Psi} = \left(\mathbf{1}_{pa} - \boldsymbol{\Lambda}\right) . * \tilde{\boldsymbol{\Psi}} + \boldsymbol{\Pi} . * \left(\mathbf{1}_{pp} * (\boldsymbol{\Lambda} . * \tilde{\boldsymbol{\Psi}})\right)$
6. Check if $\sum_{j=1}^{\#^p} \sum_{k=1}^{\#^a} \Psi^{jk} (p^j)^{1-\epsilon} = 1$, and adjust $w$ until it holds.

# Computation: aggregate dynamics (perturbation)

- Dynamic Bellman equation:

$$\mathbf{V}_t = \mathbf{U}_t + \beta E_t \left[ \frac{u'(C_{t+1})}{u'(C_t)} \mathbf{R}'_{t+1} \left( \mathbf{V}_{t+1} + \mathbf{G}_{t+1} \right) \mathbf{S} \right]$$

- Distributional dynamics:
  - $\tilde{\mathbf{\Psi}}_t = \mathbf{R}_t \mathbf{\Psi}_{t-1} \mathbf{S}'$
  - $\mathbf{\Psi}_t = \left( \mathbf{1}_{pa} - \mathbf{\Lambda}_t \right) .* \tilde{\mathbf{\Psi}}_t + \mathbf{\Pi}_t .* \left( \mathbf{1}_{pp} * \left( \mathbf{\Lambda}_t .* \tilde{\mathbf{\Psi}}_t \right) \right)$
- Collect variables in vector: $X_t = (vec(\mathbf{\Psi}_{t-1}), vec(\mathbf{V}_t), C_t, \pi_t, M_{t-1})$
- Model: $E_t \mathcal{F} \left( X_{t+1}, X_t, z_{t+1}, z_t \right) = 0$
- Linearization: $E_t \mathcal{A} \Delta X_{t+1} + \mathcal{B} \Delta X_t + E_t \mathcal{C} z_{t+1} + \mathcal{D} z_t = 0$
- Solve with Klein's QZ method for linear RE models

# CALIBRATION

# Common parameters (same in all specifications)

| | | |
|---|---|---|
| Discount factor | $\beta^{-12} = 1.04$ | Golosov-Lucas (2007) |
| CRRA | $\gamma = 2$ | Ibid. |
| Labor supply | $\chi = 6$ | Ibid. |
| MIUF coeff. | $\nu = 1$ | Ibid. |
| Elast. subst. | $\epsilon = 7$ | Ibid. |
| Money growth | $\mu = 1$ | AC Nielsen dataset: zero inflation |
| Persistence prod. | $\rho = 0.95$ | Blundell-Bond (2000) |
| Std. dev. prod. | $\sigma = 0.06$ | Eichenbaum et. al. (2009) |

# Estimated parameters for each specification

Estimation criterion:

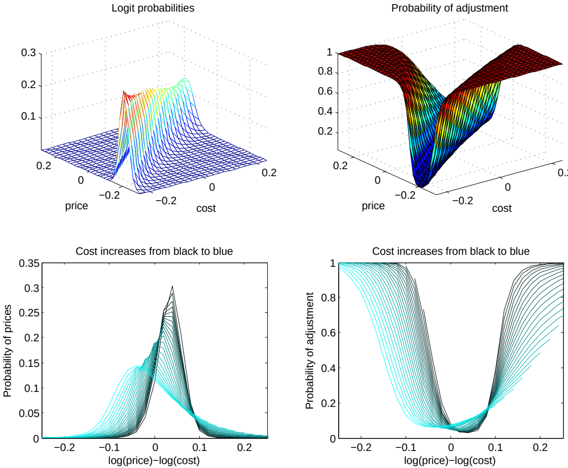
$$\text{distance} \;=\; \sqrt{n}||\lambda_{model} - \lambda_{data}|| + ||h_{model} - h_{data}||$$

where $\lambda$ = frequency, $h$ = histogram of changes, $n$ = length($h$).

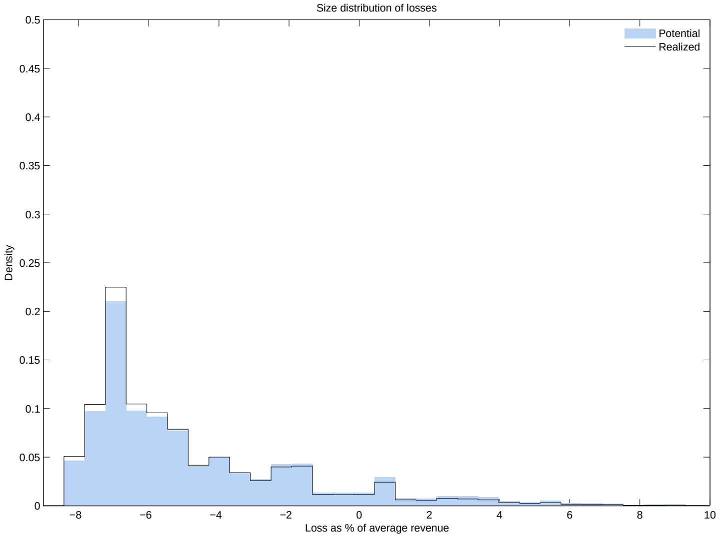
| *Specification* | Rate: $\bar{\lambda}$ | Noise: $\kappa_\pi$ | Noise $\kappa_\lambda$ |
|---|---|---|---|
| PPS-logit | – | 0.049 | – |
| PPS-control | – | 0.0044 | – |
| Woodford-logit | 0.044 | – | 0.0051 |
| Woodford-control | 0.045 | – | 0.0080 |
| Nested-logit | 0.083 | 0.013 | 0.013 |
| Nested-control | 0.22 | 0.018 | 0.018 |

# RESULTS

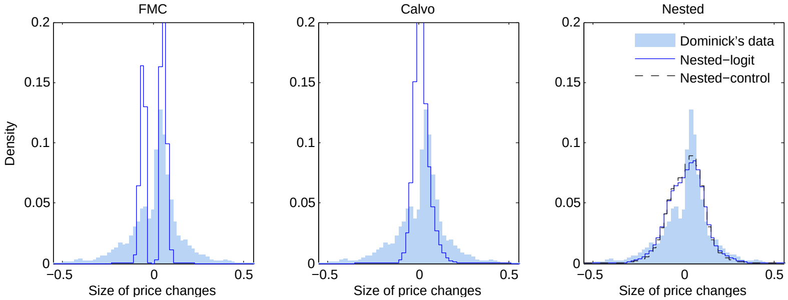
# Equilibrium behavior (Nested control-cost model)



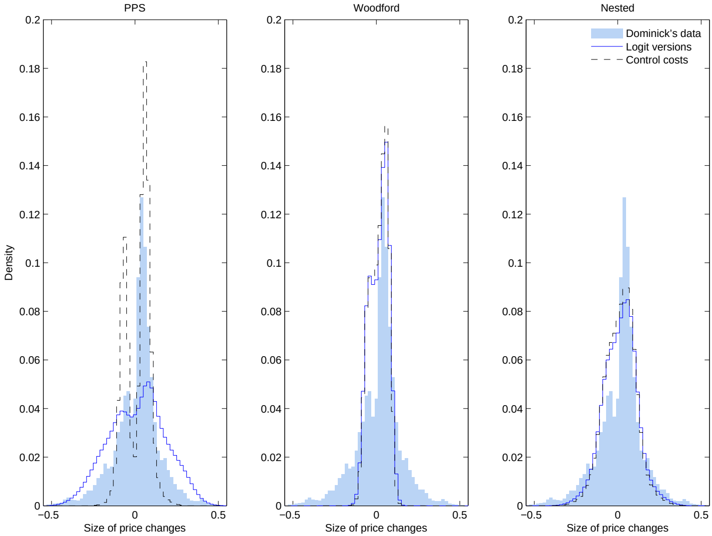
# Losses from nonadjustment (Nested control-cost model)



# Histogram of nonzero price changes (comparing models)



# Histogram of nonzero price changes (decomposing logit)



# Steady-state: statistics on price variability

| | Wdfd logit | Wdfd cntrl | PPS logit | PPS cntrl | Nest logit | Nest cntrl | Data |
|---|---|---|---|---|---|---|---|
| $Std(p)/Std(a)$ | 95.2 | 91.0 | 113 | 97.7 | 109 | 104 | 115 |
| Freq. $\Delta p$ | 10.2 | 10.2 | 10.2 | 10.2 | 10.2 | 10.2 | 10.2 |
| Mean $\lvert\Delta p\rvert$ | 4.88 | 4.68 | 14.0 | 6.72 | 8.11 | 7.51 | 9.90 |
| $Std(\Delta p)$ | 5.51 | 5.27 | 17.0 | 7.32 | 10.1 | 9.30 | 13.2 |
| $Kurt(\Delta p)$ | 2.24 | 2.22 | 2.58 | 2.37 | 3.48 | 3.40 | 4.81 |
| % $\Delta p > 0$ | 62.7 | 63.3 | 55.2 | 62.3 | 58.3 | 58.8 | 65.1 |
| % $\lvert\Delta p\rvert \leq 0.05$ | 47.9 | 49.7 | 16.5 | 27.9 | 31.5 | 33.6 | 35.4 |

Note: Statistics in percent.

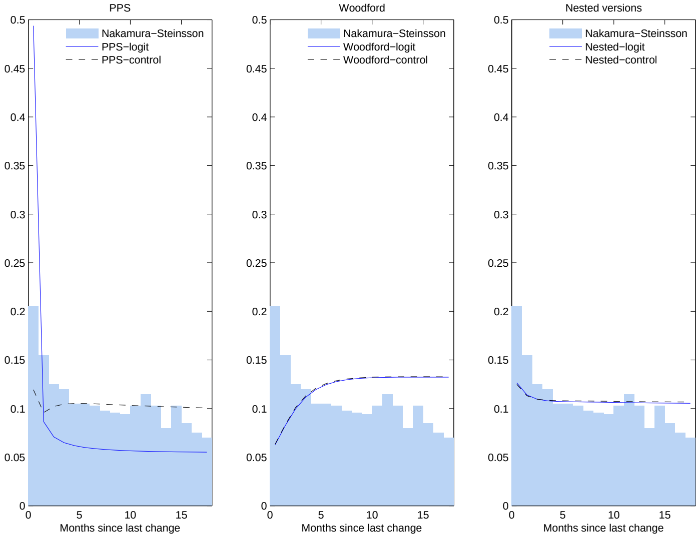
Dominick's data: "regular" price changes, excluding sales.

# Steady-state: Costs of decision-making

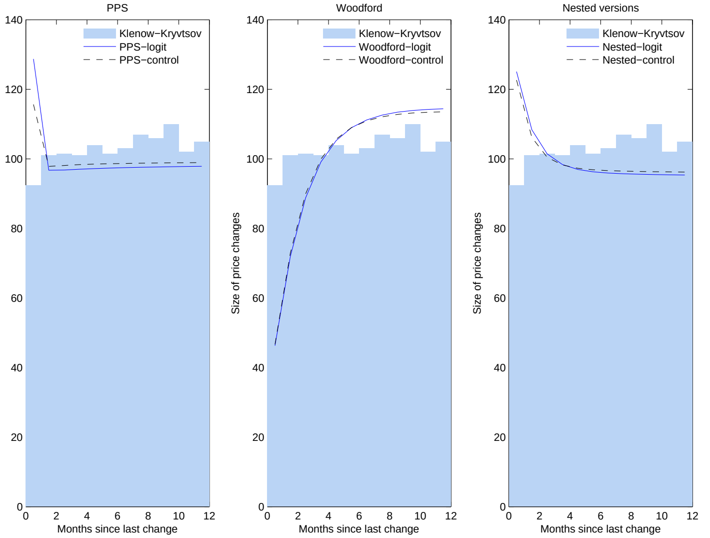
| | Wdfd logit | Wdfd cntrl | PPS logit | PPS cntrl | Nested logit | Nested cntrl |
|---|---|---|---|---|---|---|
| Pricing costs | 0 | 0 | 0 | 0.174 | 0 | 0.509 |
| Timing costs | 0 | 0.167 | 0 | 0 | 0 | 0.361 |
| Gain if rational | 0.258 | 0.416 | 0.665 | 0.365 | 0.582 | 1.41 |

Note: Costs and gains stated as percentage of average revenue.

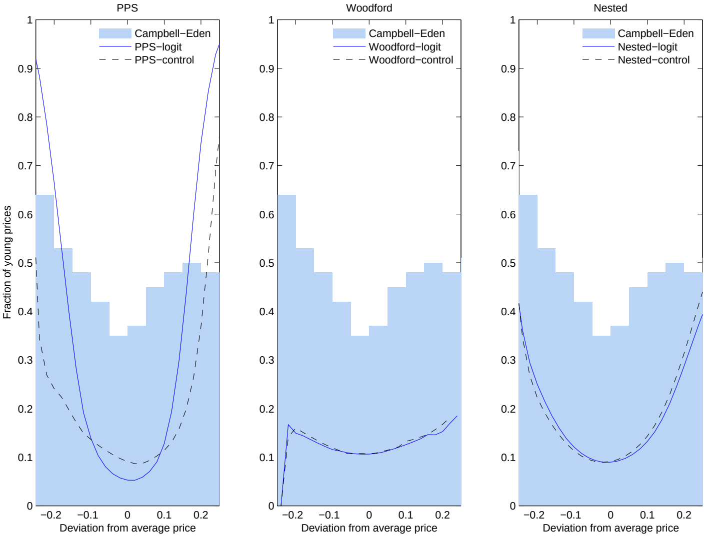
# Price adjustment hazard



# Size of price change as function of price age



# Fraction of young prices



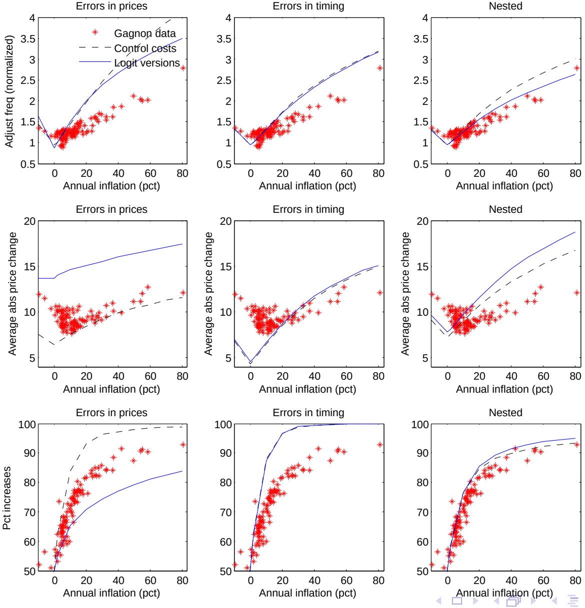
# Effects of trend inflation

| | Wdfd logit | Wdfd cntrl | PPS logit | PPS cntrl | Nest logit | Nest cntrl | Data |
|---|---|---|---|---|---|---|---|
| Freq. $\Delta p$, ratio* | 2.90 | 3.23 | 3.21 | 3.55 | 2.42 | 2.76 | 1.58 |
| Std($\Delta p$), ratio* | 0.88 | 0.75 | 1.18 | 0.72 | 1.16 | 1.02 | 0.88 |
| % $\Delta p > 0$, $\pi = 4\%$ | 65.3 | 65.2 | 58.0 | 64.3 | 62.3 | 62.9 | 76 |
| % $\Delta p < 0$, $\pi = 63\%$ | 99.9 | 99.9 | 78.5 | 98.9 | 93.3 | 94.9 | 94 |

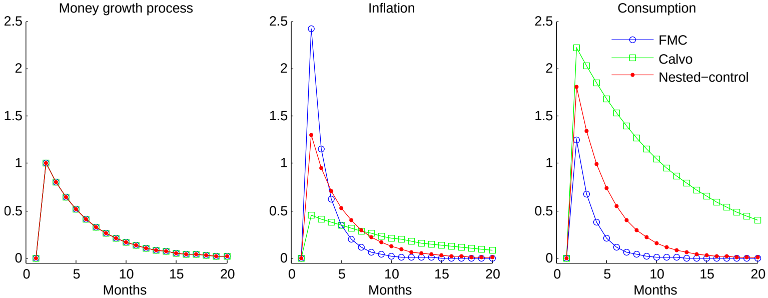
Data from Gagnon (2009): Mexican price adjustments with 4% and 63% inflation rates.

*First two lines state ratio of statistics for high and low inflation.

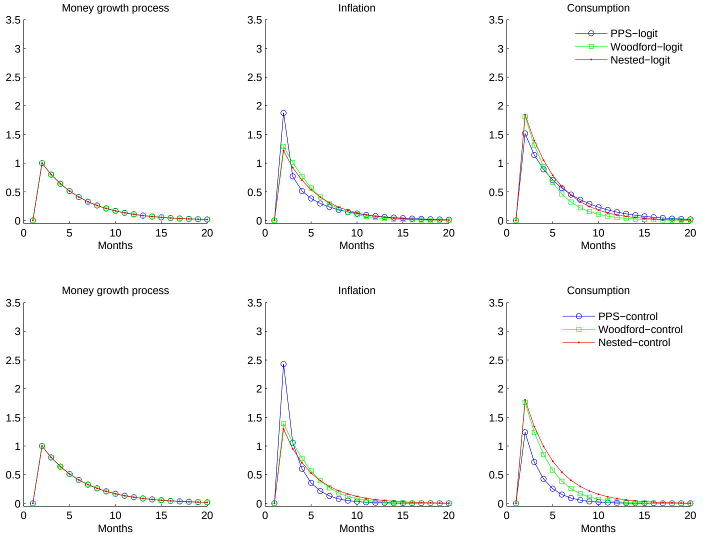
# Effects of trend inflation



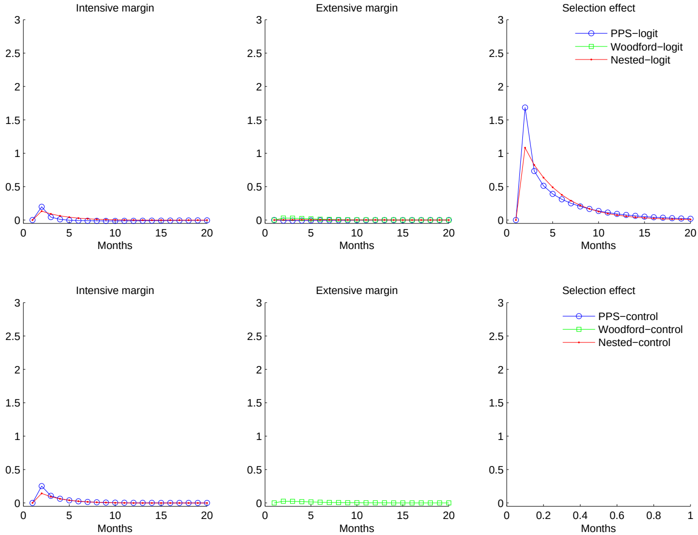
# Responses to a money growth shock (comparing models)



# Responses to a money growth shock (decomposing logit)



# Selection effect is dominant at low trend inflation rates



# Estimated Phillips curve coefficients

Table 3. Variance decomposition and Phillips curves

| *Money shocks*: ($\phi_z = 0.8$) | Wdfd logit | Wdfd cntrl | PPS logit | PPS cntrl | Nest logit | Nest cntrl | Data* |
|---|---|---|---|---|---|---|---|
| Std $\mu$ (%) | 0.16 | 0.16 | 0.16 | 0.12 | 0.17 | 0.16 | |
| Std inflation (%) | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 |
| % explained by $\mu$ | 100 | 100 | 100 | 100 | 100 | 100 | |
| Std output (%) | 0.41 | 0.41 | 0.34 | 0.20 | 0.45 | 0.40 | 0.51 |
| % explained by $\mu$ | 80 | 81 | 67 | 38 | 89 | 79 | |
| Phillips slope* | 0.32 | 0.33 | 0.31 | 0.15 | 0.38 | 0.33 | |

# CONCLUSIONS

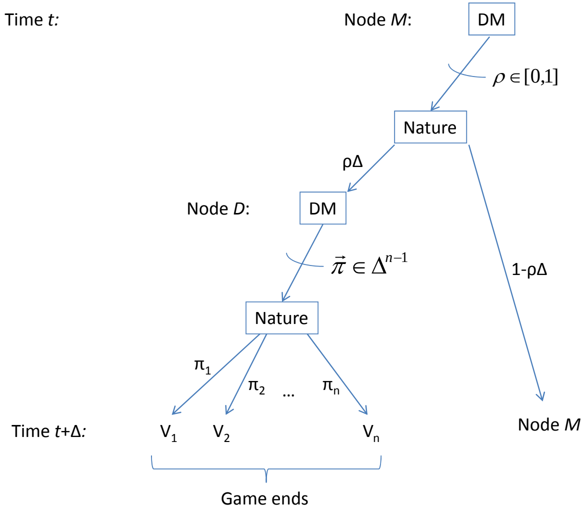
# Conclusions

- Model **nominal rigidity** based on **costly decision making**
  - Costs $\propto$ entropy $\rightarrow$ decisions are logit
- Show how to model **costly decisions of timing**
  - Two parameters required, measuring **speed** and **accuracy** of decisions
- Calibrate the two free parameters to match micro data:
  - **Price errors** help match micro facts
  - **Timing errors** help generate monetary nonneutrality
    - PPS case has just one free parameter so it cannot *in general* match both distribution and frequency
  - Also behaves well with high trend inflation
- Tractable enough to compute in DSGE
  - Like Sims (2003) and Woodford (2009), but avoid individual priors

# Extensions

- **Many possible applications:** wherever decision-makers **update a number or vector intermittently**
- Currently working on model with state-dependent **prices and wages**
- Currently working on **sequential bargaining games**
  - Costly decision-making interpreted as **time used up in the game**
- Currently working on **continuous-time limit** of this framework
- Some future applications:
  - Decision to enter or exit export markets
  - Search and matching models

# One costly decision in real time



THANKS!