Economics 742 Price Ridigity Bonus Lecture 3: Persistence and Real Rigidity

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The Persistence Puzzle

- In the last two classes we discussed the literature on state-dependent pricing models.
  - The world is not Calvo.
  - But Calvo is a decent approximation, and we can calibrate to the frequency of price changes excluding sales.
- Unfortunately, this means most prices have been reset after 8-10 months.
  - But evidence on non-neutrality suggests stickiness lasts longer.
  - And NK models need it to last longer.
  - What makes the price level (or inflation) so persistent?

Real Rigidities

- New Palgrave Dictionary of Economics (David Romer): "Real rigidities are forces that reduce the responsiveness of firms' profit-maximizing prices to variations in aggregate output resulting from variations in aggregate demand. Real rigidities make firms less inclined to take actions that dampen movements in aggregate output, and so increase the responsiveness of output to disturbances. They appear essential to any successful explanation of short-run macroeconomic fluctuations."
- Real rigidities make real wages and prices adjust by less.
  - If prices and wages are flexible, they (typically) do nothing.
  - Instead, they *amplify nominal rigidities*, generating significant aggregate stickiness from small nominal adjustment costs.
- We will focus on real rigidities in the product market.

Outline

1. Strategic Complementarity and Real Rigidity
2. Forms Of Strategic Complementarity
3. Other Sources of Persistence
4. Indirect Evidence on Real Rigidity
5. More Direct Evidence on Real Rigidity
6. Evaluation
7. Bonus Material (Cutting Room Floor)

Cooper and John (1988): Strategic Complementarity

- Cooper and John (1988) introduce idea that *strategic complementarities* can be basis for macroeconomic stickiness.
  - Refers to interactions between agents in optimal strategies.
- In pricing game, with optimal price p_{it} and price index (or price of competitor) P_t:
  - $\frac{\partial p_{it}}{\partial P_t} > 0$ strategic complements.
  - $\frac{\partial p_{it}}{\partial P_t} < 0$ strategic substitutes.

Cooper and John (1988): Coordination Failure

- Without a *coordination failure*, strategic complementarity has no effect.
  - P_t jumps to new steady state immediately, $\frac{\partial p_{it}}{\partial P_t}$ does not delay adjustment.
- With coordination failure, increased stickiness. Examples:
  - Staggered pricing.
  - Incomplete information and learning.
  - Small fraction of rule-of-thumb price setters.
- In Nash equilibrium P_t adjust partially. If $\frac{\partial p_{it}}{\partial P_t} > 1$, p_{it} adjusts partially, which aggregates to P_t to adjusting partially.
  - Would not be equilibrium if could coordinate.
  - Potential for multiple equilibria (not focus today, but something to watch out for).

Intuition With Taylor or Calvo Pricing

- Some others have not changed price.
- Strategic complementarity $\Rightarrow$ when change, adjust partially.
- Repeated partial adjustment $\Rightarrow$ additional stickiness.
- Sometimes this intuition is called a *contract multiplier* due to Taylor's (1980) staggered pricing model.
  - Prices depend on other prices (he was thinking of union wage contracts) and market conditions (ad hoc).
  - Persistence of aggregate wage stickiness outlasts duration of all contracts $\Rightarrow$ contract multiplier.

Ball and Romer's Index of Real Rigidity

- Consider a (static) profit function:

$$\Pi\left(p_{it}/P_t, M_t/P_t, A_{it}\right)$$
$$FOC: \ \Pi_1\left(p_{it}/P_t, M_t/P_t, A_{it}\right) = 0.$$

- Ball and Romer's (1990) measure of real rigidity is:

$$\frac{d\left(p_{it}/P_t\right)}{d\left(M_t/P_t\right)} = \frac{\Pi_{12}}{-\Pi_{11}} = \Psi$$

  - Real rigidity is higher when Ψ is *lower*, so prices are less responsive to aggregate demand.

- We see real rigidity can come from two sources:

1. $-\Pi_{11}$: Increased concavity of profit function in relative price.
2. Π_{12}: Smaller interaction between agg demand and rel price.

Ball and Romer's Index of Real Rigidity

- Kimball (1995) extends to dynamic case. Here I use Basu's (2005, JME) discrete-time formulation.
- With Calvo (θ) pricing, NK Phillips Curve in log deviations:

$$\hat{\pi}_t = \beta E_t \hat{\pi}_{t+1} + \theta^2 \Psi \hat{mc}_t$$

- Sometimes Ψ is written as $\Psi = \frac{\Omega}{\varepsilon\omega}$:
  - ε is steady state demand elasticity.
  - $\Omega = \left. \frac{\partial \log(MC_t(i)/MR_t(i))}{\partial \log Y_t(i)} \right|_{d \log Y_t = d \log Y_t(i)}$
  - $\omega = \left. \frac{\partial \log(MC_t(i)/MR_t(i))}{\partial \log Y_t(i)} \right|_{d \log Y_t = 0}$
  - Ω is elasticity of MC/MR wrt y for coordinated increase in $y_t(i)$, ω is elasticity for unilateral increase in $y_t(i)$.
  - $-\Pi_{11} = \varepsilon\omega$, $\Pi_{12} = \Omega$.

Relation to Strategic Complementarity

$$\Pi\left(p_{it}/P_t, M_t/P_t, A_{it}\right)$$
$$FOC: \ \Pi_1\left(p_{it}/P_t, M_t/P_t, A_{it}\right) = 0.$$

- Solve for $\frac{\partial p_{it}}{\partial P_t}$

$$\Pi_{11}\left(\frac{1}{P_t}\frac{\partial p_{it}}{\partial P_t} - \frac{p_{it}}{P_t^2}\right) - \Pi_{12}\frac{M_t}{P_t^2} = 0$$
$$\frac{\partial p_{it}}{\partial P_t} = \frac{p_{it}}{P_t} + \frac{\Pi_{12}}{\Pi_{11}}\frac{M_t}{P_t}$$

- Normalize $M_t/P_t = 1$ and consider $p_{it}/P_t = 1$ in steady state:

$$\frac{\partial p_{it}}{\partial P_t} = 1 + \frac{\Pi_{12}}{\Pi_{11}}$$

Relation to Strategic Complementarity

$$\Pi\left(p_{it}/P_t, M_t/P_t, A_t\right), \frac{\partial p_{it}}{\partial P_t} = 1 + \frac{\Pi_{12}}{\Pi_{11}}$$

- p_{it} and P_t are strategic complements if:

$$\frac{\partial p_{it}}{\partial P_t} > 0 \Rightarrow \Psi = \frac{\Pi_{12}}{-\Pi_{11}} < 1$$

- In Nakamura and Steinsson's (2013) terminology:
  - $-\Pi_{11}$ controls degree *micro strategic complementarity.*
    - Lower incentive to raise price as price rises relative to others.
    - Examples: Demand system, fixed factors.
  - Π_{12} controls degree of *macro strategic complementarity*.
    - Lower incentive to raise price as aggregate demand changes.
    - Examples: Real wage rigidity, intermediate inputs.
- Lots of different terminologies: some only call micro "strategic complementarity."

Real Rigidity in Standard RBC

- In standard RBC calibrations with CRS production and homogenous factors of production, real rigidity is very low.
  - In fact, with IES < 1, have strategic substitutes.
  - Output insensitive to shocks because prices adjust quickly.
  - Calvo is weak because if others stuck at old price you have an incentive to raise your price quickly, making agg price level more flexible.

- To see this, consider a simple RBC model with a cash in advance constraint.
  - Utility $\frac{C_t^{\mathbf{1}-\sigma}}{1-\sigma} - \frac{L_t^{\mathbf{1}+\phi}}{1+\phi} \Rightarrow$ labor-leisure $C_t^{\sigma} L_t^{\phi} = \frac{W_t}{P_t}$.
  - With $Y_t = A_t L_t$, $C_t = Y_t$, $M_t = P_t Y_t$ this gives:

$$W_t = \frac{P_t Y_t^{\sigma+\phi}}{A_t^{\phi}} = \frac{M_t Y_t^{\sigma+\phi-1}}{A_t^{\phi}}$$

Real Rigidity in Standard RBC

$$\begin{aligned} MC_t &= \frac{W_t}{A_t} = \frac{M_t Y_t^{\sigma+\phi-1}}{A_t^{1+\phi}} \\ \hat{mc}_t &= \hat{m}_t + (\sigma+\phi-1)\,\hat{y}_t - (1+\phi)\,\hat{a}_t \end{aligned}$$

- Marginal revenue is $MR_t = P_t = M_t/Y_t \Rightarrow \hat{mr}_t = \hat{m}_t - \hat{y}_t$.
- Recall $\Pi_{12} = \Omega = \left.\frac{\partial \log(MC_t(i)/MR_t(i))}{\partial \log Y_t(i)}\right|_{d\log Y_t = d\log Y_t(i)}$ so

$$\begin{aligned} \hat{mc}_t - \hat{mr}_t &= (\sigma+\phi)\,\hat{y}_t - (1+\phi)\,\hat{a}_t \\ \Omega &= \sigma+\phi \end{aligned}$$

- If the IES $<1 \Rightarrow \sigma > 1$, have $\Omega > 1$ regardless of ϕ.

Forms of Strategic Complementarity

- Strategic complementarity can take many forms.
- From Basu (2005):

Table 1
Examples of Ω and ω mechanisms

	Marginal cost	Marginal revenue
Ω	Variable capital utilization Elastic labor supply Efficiency wages *Sticky nominal wages* *Sticky intermediate goods prices*	Countercyclical target markups
ω	*Factor attachment*	*Kinked demand curves*

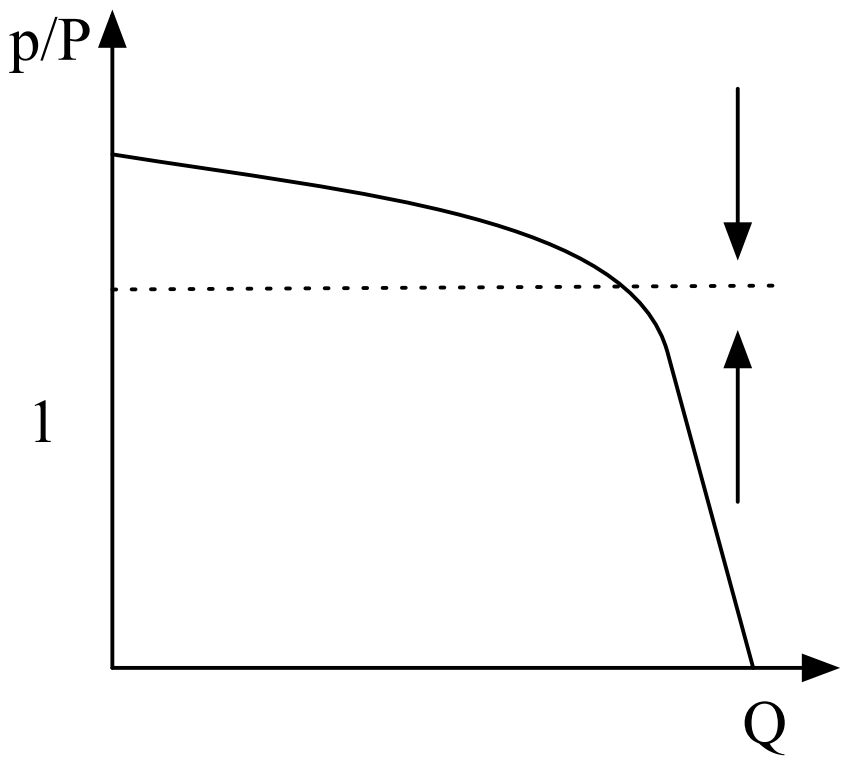
- I will discuss a few of the most widely-used sources of strategic complementarity:
  1. Demand System (Type Π_{11})
  2. Heterogenous Factor Markets / Fixed Factors (Type Π_{11})
  3. Intermediate Inputs (Type Π_{12})
  4. Other Type Π_{12}

Forms of Type Π_{11} (Micro) Real Rigidity

- Demand System
- Heterogeneous Factor Markets / Fixed Factors
- Oligopoly in Product Markets
- Countercyclical markups for other reasons (won't cover).

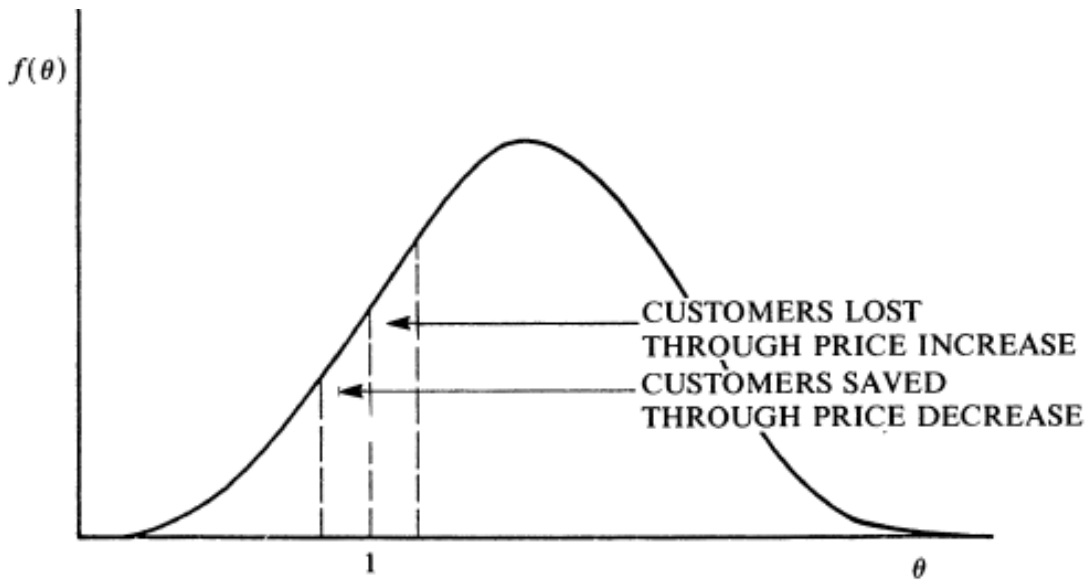
"Smoothed-Out Kink" or "Concave" Demand

- Consider a demand curve that is concave to the origin with curvature around relative price of 1.
- Elasticity increasing in $\frac{p_{it}}{P_t} \Rightarrow$ markup and optimal price decreasing in $\frac{p_{it}}{P_t} \Rightarrow$ incentive to price close to average.



"Smoothed-Out Kink" or "Concave" Demand

- Ball and Romer (1990) introduce a "customer markets" style microfoundation (others have built on this).
  - Price increase drives away your customers, but decrease does not attract new customers because customers of other sellers do not observe it.
  - Hazard rate of distribution of when customers walk away gives curvature:



Kimball (1995) Tractable Demand System

- Kimball (1995) introduces a frequently-used and tractable generalization of Dixit-Stiglitz that allows for concave demand.
- Consider a CRS consumption aggregator that satisfies:

$$1 = \int_0^1 \Upsilon\left(y_t\left(i\right)/Y_t\right) di$$

$\Upsilon\left(1\right) = 1$, $\Upsilon'\left(\xi\right) > 0$, $\Upsilon''\left(\xi\right) < 0 \; \forall \; \xi = y_t\left(i\right)/Y_t > 0$.

  - Nests Dixit-Stiglitz: $\Upsilon = \xi^{\frac{\theta-\mathbf{1}}{\theta}}$
  - Pick Υ to get desired shape of demand curve.

- Lower-level household problem is:

$$\min_{y_t(i)} \int_0^1 p_t\left(i\right) y_t\left(i\right) di \text{ s.t. } 1 = \int_0^1 \Upsilon\left(y_t\left(i\right)/Y_t\right) di$$

$$FOC: \; p_t\left(i\right) = \frac{\Lambda}{Y_t} \Upsilon'\left(y_t\left(i\right)/Y_t\right)$$

Kimball (1995) Tractable Demand System

$$p_t(i) = \frac{\Lambda}{Y_t} \Upsilon'(y_t(i)/Y_t)$$

- The inverse elasticity of demand is then equal to

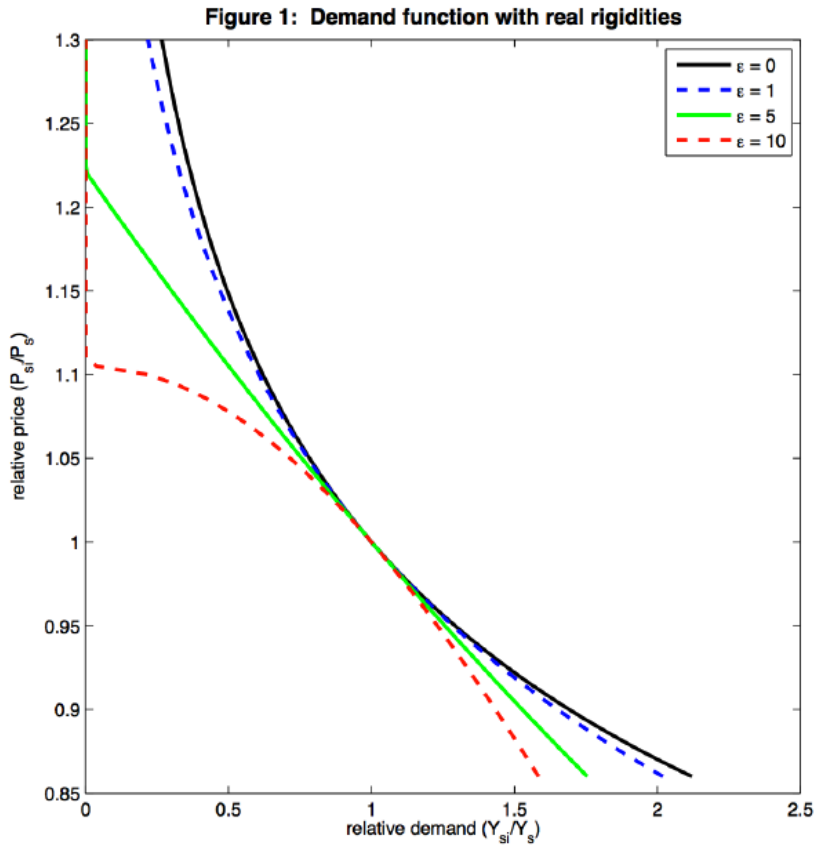
$$\begin{aligned} 1/\epsilon(\xi) &= -y_t(i) \frac{d \log p_t(i)}{d y_t(i)} \\ &= -\frac{\xi \Upsilon''(\xi)}{\Upsilon'(\xi)} \end{aligned}$$

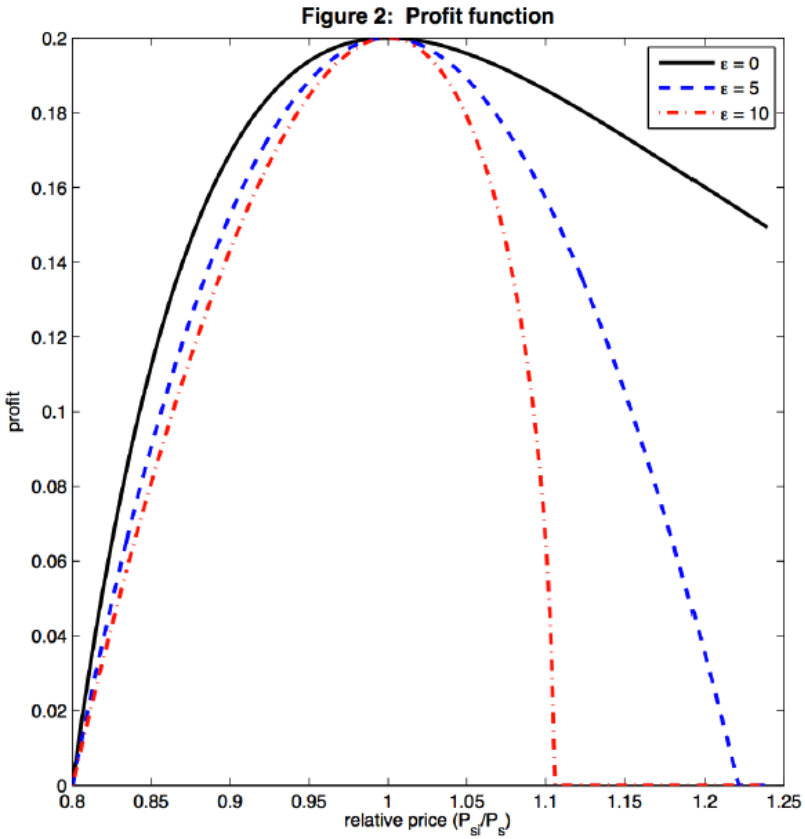
- The "super elasticity" of demand is the elasticity of the elasticity $\frac{d \log \epsilon(\xi)}{d \log \xi}$:

$$\epsilon^{super}(\xi) = 1 - \frac{\Upsilon'(\xi)}{\xi \Upsilon''(\xi)} - \frac{\Upsilon'(\xi) \Upsilon'''(\xi)}{\Upsilon''(\xi)^2}$$

- See Klenow and Willis (2016) for a tractable function for $\Upsilon(\cdot)$ that allows for an arbitrary amount of curvature.

Kimball Demand and Profit Function





Source: Klenow and Willis (2016)

Atkeson and Burstein (2008): Imperfect Competition

- A frequently-used (especially in international macro) alternative that also generates strategic complementarity.
- Consumption good produced by competitive firm with CES tech using inputs from continuum of sectors j:

$$c = \left[\int_0^1 y_j^{1-1/\eta} \right]^{\eta/(\eta-1)}$$

- Within sectors K firms selling distinct goods combined by firm with CES tech

$$y_j = \left[\sum_{k=1}^{K} (q_{jk})^{(\rho-1)/\rho} \right]^{1/(1-\rho)}$$

- Marginal cost is MC_{jk}.

Atkeson and Burstein (2008): Imperfect Competition

- Assume $1 < \eta < \rho < \infty$: goods within sectors are imperfect substitutes but goods within sectors are more substitutable than goods across sectors.
- Also assume firms play *static* game of Cournot competition

$$\max_{P_{jk}, q_{jk}} P_{jk} q_{jk} - q_{jk} \frac{W}{A z_{jk}} \text{ s.t. } \frac{P_{jk}}{P} = \left(\frac{q_{jk}}{y_j} \right)^{-1/\rho} \left(\frac{y_j}{c} \right)^{-1/\eta}$$

taking P, c,MC_{jk} and $q_{jl} \forall l \neq k$ as given.

Atkeson and Burstein (2008): Imperfect Competition

$$P_{jk} = \frac{\varepsilon\left(s_{jk}\right)}{\varepsilon\left(s_{jk}\right) - 1} MC_{jk} \text{ with } \varepsilon\left(s\right) = \left[\frac{1}{\rho}\left(1 - s\right) + \frac{1}{\eta}s\right]^{-1}$$

where s is market share:

$$s = \frac{P_{jk} q_{jk}}{\sum_{l=1}^{K} P_{jl} q_{jl}} = \frac{P_{jk}^{1-\rho}}{\sum_{l=1}^{K} P_{jl}^{1-\rho}}$$

- Markup is variable between $\frac{\rho}{\rho-1}$ and $\frac{\eta}{\eta-1}$:
  - If $s \to 0$ (continuum of firms), elasticity $\to \rho$.
  - If $s \to 1$, elasticity $\to \eta$.
  - In between, elasticity rises towards ρ as market share falls, eroding markup.
- Since market share is decreasing in relative price, creates strategic complementarity.
- In practice, need $\eta \approx 1$ and ρ large (about 10) for this to work.

Heterogenous Factor Markets

- Rotemberg (1996), Woodford (2003, 2004, 2005) and Altig et al. (2011) show that relaxing assumption of homogenous factors of production creates strategic complementarity.
  - Firm-specific labor or capital (Woodford).
  - Adjustment costs in capital or labor.
  - Pre-determined capital (Altig et al.).
  - Decreasing returns.

- Intuitively, this makes a firm's marginal cost increase in its relative output and decrease in relative price.
  - Higher price $\Rightarrow$ less demand and output $\Rightarrow$ reduces MC $\Rightarrow$ pushes optimal price down.
  - Recall that $-\Pi_{11} = \varepsilon\omega$ where $\omega = \left.\frac{\partial \log(MC_t(i)/MR_t(i))}{\partial \log Y_t(i)}\right|_{d \log Y_t = 0}$ so marginal cost increasing in $Y_t(i)$ makes $-\Pi_{11}$ larger.
  - Mirror image to what concave demand did to $MR_t(i)$.

Heterogenous Factor Markets: Woodford (2003)

- Version you will see a lot is specific types of labor and DRS.
- Goods produced with production function $y_t(i) = A_t f(L_t(i))$
  - Creates increasing marginal cost of production as

$$MC_t(i) = \frac{w_t(i)}{A_t} \frac{1}{f'(f^{-1}(y))}$$

  - MC increasing if f is DRS or $w_t(i)$ increasing in $y_t(i)$.
- To get $w_t(i)$ increasing in $y_t(i)$, households supply all types of labor with disutility $v(L_t)$ where $L_t = \left[\int_0^1 L(i)_t^{\frac{\nu-1}{\nu}} di\right]^{\frac{\nu}{\nu-1}}$.
  - To increase $\frac{L_t(i)}{L_t}$ have to increase $\frac{w_t(i)}{w_t}$ where w_t is wage index.
- Based on previous discussion of RBC, fixed/heterogenous factors reduce strategic substitutability in typical calibrations.

Oligopoly in Product Markets

- Mongey (2019) shows that imperfect competition in product markets can also generate micro strategic complementarity.
- Ingredients for *dynamic strategic complementarity*:
  1. Static strategic complementarity.
     - Comes from high substitutability within industry.
  2. Menu Costs
     - Wipes out small gains from best responses (Bertrand).
  3. Dynamic Oligopoly
     - Post high price knowing competitor can and will follow in future.
     - Menu costs makes this a credible strategy.
- Mongey implements with a continuum of duopolies.
  - Essentially a modification of Golosov-Lucas.
  - Solves with Krusell-Smith.

Forms of Type Π_{12} (Macro) Real Rigidity

- Intermediate Inputs
- Sticky Wages
- Variable Capital Utilization
- GHH Preferences

Intermediate Inputs: Basu (1995) Roundabout Production

- Basu (1995) adds intermediate inputs through "roundabout" production structure:

$$y_{it} = L_{it}^{\alpha} Y_t^{1-\alpha}$$

  - Y_t is a CES aggregator of y_{it}s with price index P_t.
  - Everyone's output is everyone else's input.

- In logs:

$$mc_t(i) = \alpha w_t + (1-\alpha) p_t$$

  - With constant markup μ, strategic complements as:

$$p_{it} = \mu [\alpha w_t + (1-\alpha) p_t] \Rightarrow \frac{\partial p_{it}}{\partial p_t} = \mu (1-\alpha) > 0$$

- Intuition: If adjust price soon after shock, partially adjust because price of inputs have not fully responded.

Intermediate Inputs: Basu (1995) Roundabout Production

- Results depend crucially on "roundabout" formulation.
- Contrast with Blanchard (1983).
  - Considers chains of production.
  - Gets added stickiness only because different stages are staggered to adjust at different times, so price changes "ripple down the chain."
  - No strategic complementarity because there is a "first good" in the chain whose marginal cost is unaffected by price of other goods.
- Motivates "roundabout" nature of production by large values on diagonal of input-output matrix.
- Discuss roundabout production further in a bit with Nakamura and Steinsson (2010).

Other Sources of Π_{12} Real Rigidity

- Sticky wages $\Rightarrow$ marginal costs respond slowly.
  - More of a nominal rigidity in my mind.
  - But works through Π_{12} being smaller.
- Variable capital utilization:

$$mc_t(i) = \alpha w_t + (1-\alpha)(u_t k_t)$$

  - Higher price $\Rightarrow$ less demand and output $\Rightarrow$ cut utilization u_t $\Rightarrow$ reduces MC $\Rightarrow$ pushes optimal price down.
  - Similar intuition to RBC literature: capital utilization makes MPL and wage less sensitive to the quantity of labor hired.

Other Sources of Π_{12} Real Rigidity

- GHH preferences: $u\left(c_t - v\left(l_t\right)\right) = \frac{\left(c_t - \frac{l_t^{1+\phi}}{1+\phi}\right)^{1-\sigma}}{1-\sigma}$.
  - Consumption-Labor complementarity.
  - Microfound with home production.
  - Labor-Leisure FOC: $\frac{W_t}{P_t} = l_t^{\phi}$.
- Following steps from RBC example before, $\Omega = \phi$.
  - Recall with separable utility, $\Omega = \sigma + \phi > 1$.
  - Smaller $\Omega \Rightarrow$ less strategic substitutability, more real rigidity.
  - Strategic complements if Frisch labor supply elasticity $\frac{1}{\phi}$ is high.

Take Aways

$$\frac{d\left(p_{it}/P_t\right)}{d\left(M_t/P_t\right)} = \frac{\Pi_{12}}{-\Pi_{11}} = \Psi$$

- Unifying framework to understand persistence and degree of non-neutrality in a whole framework of models.
- Direct relationship to strategic complementarity.
- Two sources $-\Pi_{11}$, Π_{12} have different intuitions, and, as we will see, different implications.

Other Sources of Persistence

- So far we have focused on coordination failures coming from Calvo / Taylor.
- We will examine whether they exist in a menu cost model soon.
- First I wanted to mention a other sources of persistence and coordination failure:

1. Sectoral Heterogeneity
2. Dispersed Information and Strategic Complementarity

Sectoral Heterogeneity: Carvalho (2006)

- Carvalho (2006) considers sectoral heterogeneity as a source of aggregate stickiness.
- Intuition: Frequency Composition Effect.
  - Initial adjustment dominated by quick adjustors.
  - Once quick-adjustors have responded, aggregate price adjustment slows dramatically because slow adjustors remain.
- Interacts with strategic complementarities.
  - Less likely those relying on competition in product markets. More likely factor markets or Π_{12} complementarity.
- Carvalho (2006) finds three times the aggregate stickiness of a representative-sector model in a Calvo framework.
- Will return to this with Nakamura and Steinsson (2010).

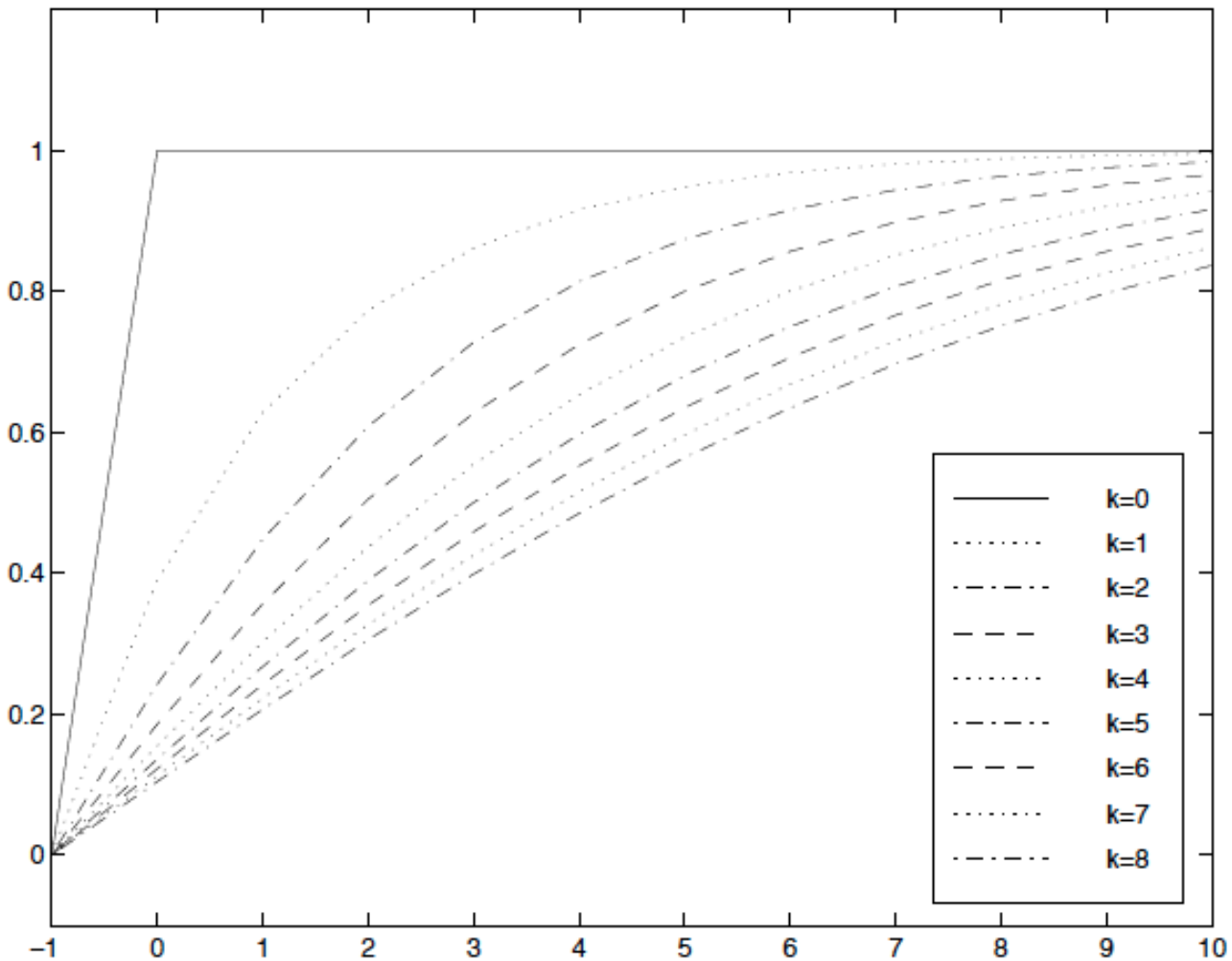
Incomplete Information and Strategic Complementarity

- Another potential source of coordination failure is incomplete information.
- Think about a Lucas Islands model.
  - Cannot tell whether aggregate money expansion or local shock. Partially respond because Bayesian.
  - Typically assume agents observe last period's fundamental.
  - For tractability one-period filtering problem.
- Could extend model by having agents repeatedly observe noisy signals about local and aggregate states.
  - Kalman Filter.
  - Bayesian learning about fundamentals occurs reasonably rapidly if signals observed frequently.
- What happens when we add strategic complementarities?

Incomplete Information and Strategic Complementarity

- What happens when we add strategic complementarities?
  - Suddenly *higher order beliefs matter.*
  - What I think that you think that I think...
- Phelps (1983): Higher order expectations slower to adjust.
  - Observation of noisy signals allow you to infer aggregate demand has increased quickly.
  - But observations provide less information about how *perceptions of others* who observed different signals changed.
  - Even less on perceptions of the perceptions of others...
- Literature on coordination failure from incomplete information.
  - See Woodford (2003) for tractable example in which incomplete info + strategic comp substitutes for Calvo.
    - Can be more persistent than Calvo.
    - Can generate hump-shaped responses.
  - Gets very difficult with endogenous signals (e.g. learning from prices not signals about fundamentals). Townsend (1983).

Higher-Order Expectations More Persistent



Source: Woodford (2001)

Evidence on Real Rigidity and Strategic Complementarity

- Strategic complementarities are nice in theory.
  - But do they exist in practice?
  - And if so how important are they?
- Contentious issue in macroeconomics.
- First we will consider indirect evidence.
  - Calibrating models.
  - Looking for fingerprints of strategic complementarity.
- Then small amounts of direct evidence.

Chari, Kehoe, and McGrattan (2000): Quantitative Calibrated Model

- Take canonical Taylor sticky price model and quantitatively assess degree of real rigidity added by:
  1. GHH Preferences.
  2. Fixed Factors
  3. Kimball Demand
- Measure with contract multiplier: ratio of half life of output deviations after monetary shock with staggering to half life with synchronized price setting.
  - With prices set every quarter, must be 20 to match data. So need about 6 with 10-month stickiness.
- Consider impact of adding inter-temporal linkages through capital and interest-sensitive money demand.

Chari, Kehoe, and McGrattan (2000): Quantitative Calibrated Model

Economy[a]	Types of Intertemporal Links: None	Only Money	Only Capital	Both
Benchmark				
2 cohorts, iid money growth	0.90	0.90	1.02	1.05
13 cohorts, serially correlated money growth	1.01	0.87	1.11	0.99
Near-Perfect Substitute Preferences[b]				
2 cohorts, iid money growth	21.97	20.00	1.07	0.50
13 cohorts, serially correlated money growth	139.10	22.72	8.31	0.13
Convex Demand				
2 cohorts, iid money growth	2.17	2.17	1.57	1.62
13 cohorts, serially correlated money growth	3.79	2.44	1.76	1.55
Specific Factors				
2 cohorts, iid money growth	1.43	1.43	1.30	1.30
13 cohorts, serially correlated money growth	1.82	1.54	1.59	1.33
Combined Model				
2 cohorts, iid money growth	1.96	1.96	1.75	1.75
13 cohorts, serially correlated money growth	3.26	2.19	2.39	1.81

Klenow and Willis (2016): Size of Price Changes

- Are strategic complementarities consistent with the large price changes one observes in micro data?
  - Klenow and Willis (2006 chronologically, published 2016) argue no.
  - Note: Cited a lot, but still working paper with rough edges.
- Write down menu cost model with Kimball (1995) preferences, estimate it to match micro data.
- Get high price level persistence and low MC pass-through, but:
  - Standard deviation of monthly innovation to firm productivity must be implausibly large: 35% of productivity.
  - Quantity very volatile. Firms frequently set price to produce no output. Seems unrealistic.
- Intuition: Strong incentive to price close to others. To get enough Δp dispersion need huge idiosyncratic shocks.

Klenow and Willis (2016): Size of Price Changes

Figure 7: Simulation of firm–level prices and output when $\varepsilon = 0$

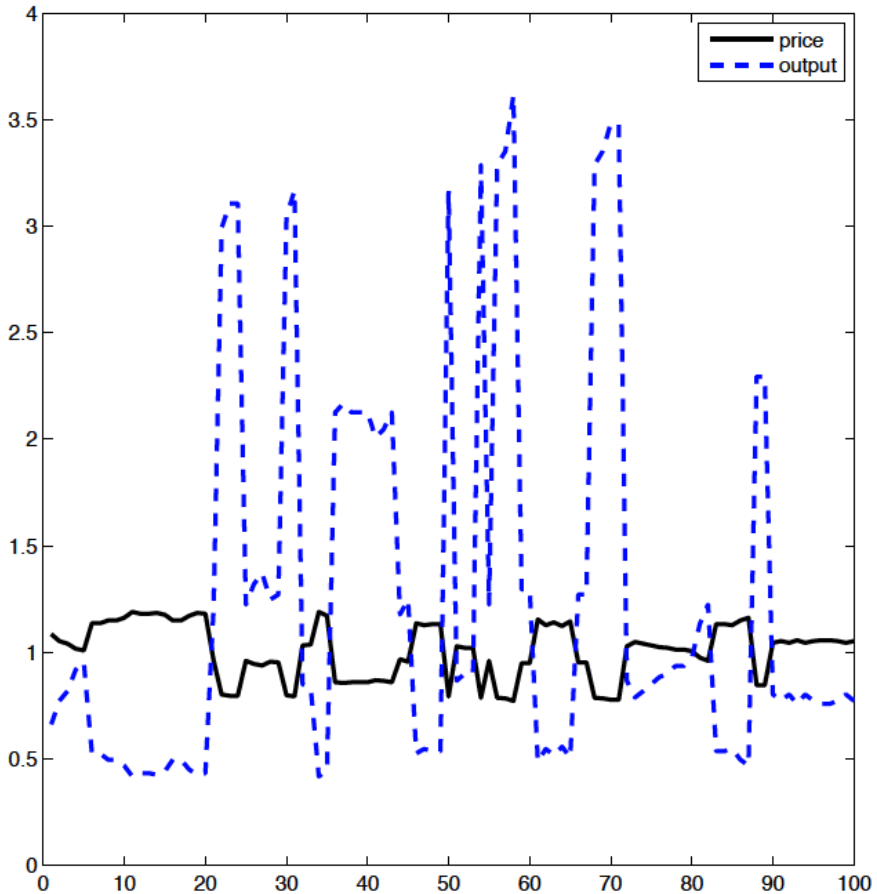
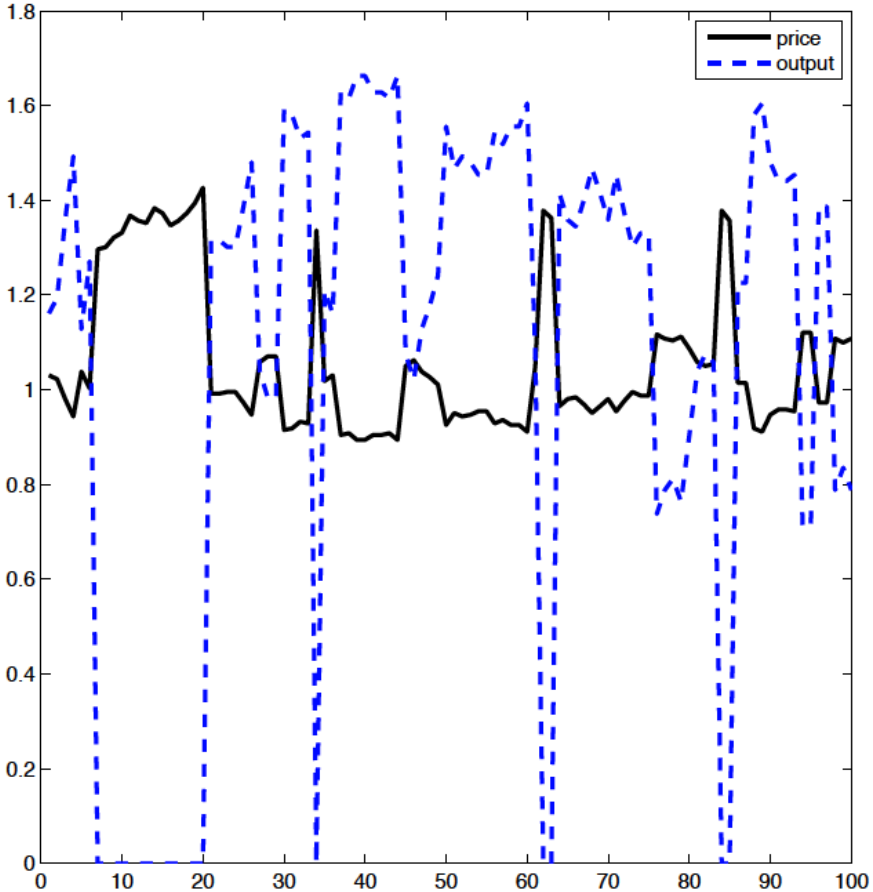


Figure 8: Simulation of firm–level prices and output when $\varepsilon = 10$



Nakamura and Steinsson (2010): A Response

- Nakamura and Steinsson (2010) argue that Klenow and Willis' argument is bad news for micro complementarity, but does not rule out macro complementarity.
- $\Pi\left(p_{it}/P_t, M_t/P_t, A_{it}\right)$. Price response to idiosyncratic shock:

$$\frac{\partial p_t}{\partial A_{it}} = \frac{\Pi_{13}}{-\Pi_{11}}$$

  - If $-\Pi_{11}$ large, mutes response of price to idiosyncratic shock.
- But this says nothing about Π_{12}.
  - Macro strategic complementarity is immune to critique.
  - So add macro complementarity to a menu cost model to refute Golosov-Lucas argument that price rigidity is fleeting.

Nakamura and Steinsson (2010): Menu Cost Model

- Menu cost model with
  1. Sectoral heterogeneity as in Carvalho (2006).
     - In menu cost model, could amplify or reduce stickiness.
     - Discipline with micro data on relationship between frequency of adjustment and size of adjustment across sectors.
     - Carvalho's intuition dominates.
  2. Roundabout production as in Basu (1995).
     - Intermediate input share hard to calibrate.
     - Use 70% based on average cost share of intermediate inputs, assumed to be same as marginal cost share.
  - Both increase monetary non-neutrality by a factor of three (together nine).
  - Neither affects the model's ability to account for the size of price changes.
- Calibrate to aggregate nominal shocks $\Rightarrow$ explains 23% of business cycle fluctuations (in line with estimates).

Nakamura and Steinsson (2010): Menu Cost Model

	Menu cost model	
	$s_m = 0$	$s_m = 0.7$
	Monetary non-neutrality: $\text{Var}(C_t)$	
One-sector model (mean)	0.055	0.182
Six-sector model	0.136	0.470
Nine-sector model	0.143	0.576
Fourteen-sector model	0.188	0.627
One-sector model (median)	0.261	0.658

Bils, Klenow, and Malin (2012): Reset Price Inflation

- Bils, Klenow, and Malin (2012) use "reset price inflation" to test models with strategic complementarities.
  - Strategic complementarity slows response of reset prices to aggregate shocks, so look at reset price behavior directly.
- Let $p_{i,t}$ be a log price of item i at time t, $\omega_{i,t}$ be its CPI weight, and $I_{i,t}$ be a price change indicator.
- The reset price level $p^*_{i,t}$ is:

$$p^*_{i,t} = \begin{cases} p_{i,t} & \text{if } p_{i,t} \neq p_{i,t-1} \\ p^*_{i,t-1} + \pi^*_t & \text{if } p_{i,t} = p_{i,t-1} \end{cases}$$

where

$$\pi^*_t = \frac{\sum_i \omega_{i,t} \left(p_{i,t} - p^*_{i,t-1} \right) I_{i,t}}{\sum_i \omega_{i,t} I_{i,t}}$$

Bils, Klenow, and Malin (2012): Reset Price Inflation

- Intuition: Like repeat sale house price index for CPI.
  - Houses price index computed by differencing transacted price with previous period's estimated value.
  - Estimated value from updating previous sale price with index.
  - One way to do this is to let the index be ψ_t in:

$$\log p_{i,t} = \phi_i + \psi_t + \varepsilon_{i,t}$$

  - BKM do alternate procedure, but behaves similarly.

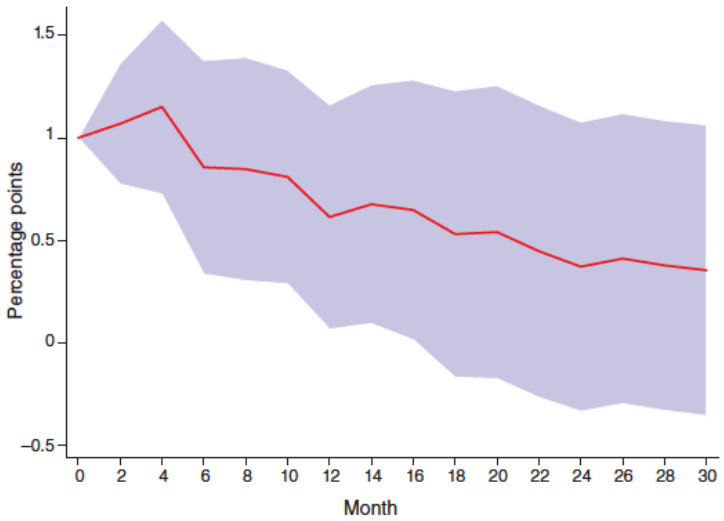
- Strategic complementarity predicts reset price inflation should be persistent.
  - Repeated partial adjustment $\Rightarrow$ persistence in π^* as reset prices build slowly.

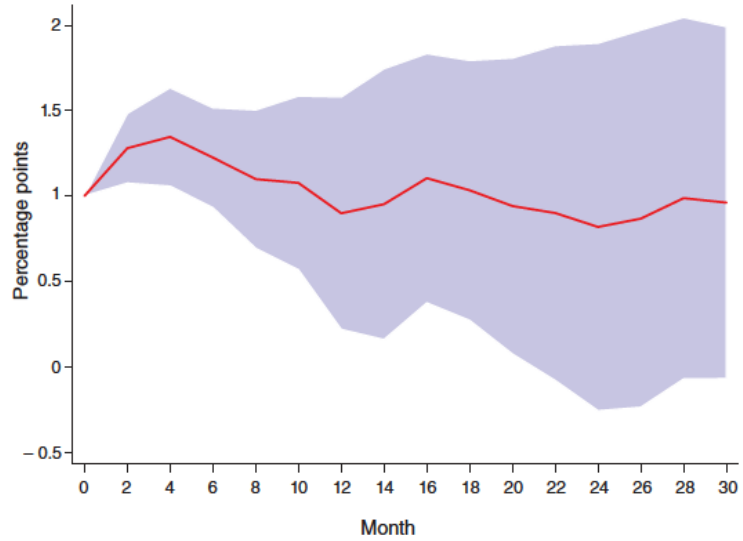
Bils, Klenow, and Malin (2012): Reset Price Inflation

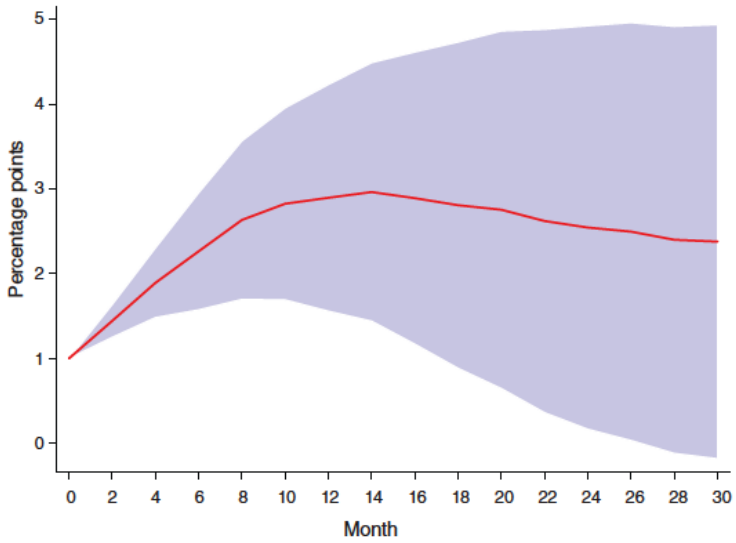
TABLE 2—SUMMARY STATISTICS FOR RESET AND ACTUAL PRICE INFLATION

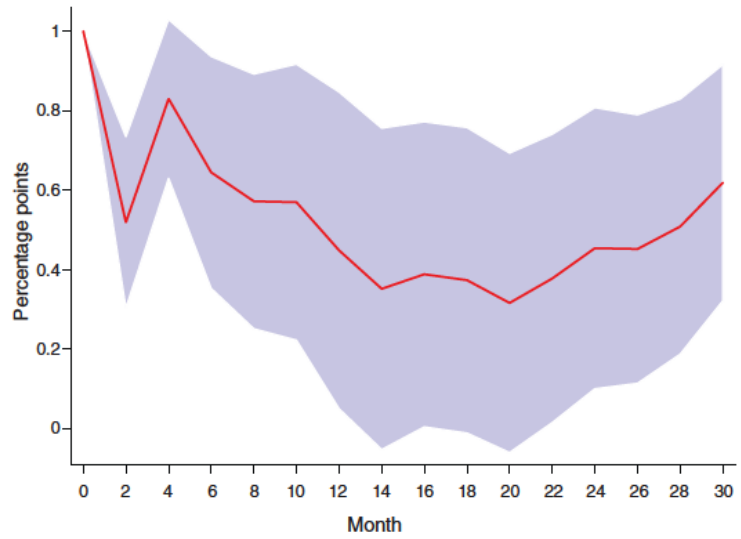
Statistic	All items	Food & energy	Core	Flexible items	Sticky items
Standard deviation of π	0.52%	1.38%	0.22%	1.44%	0.16%
	(0.03)	(0.09)	(0.01)	(0.09)	(0.01)
Serial correlation of π	0.27	0.22	0.33	0.25	0.64
	(0.09)	(0.09)	(0.13)	(0.11)	(0.07)
1-year cumulative π	0.90	0.76	1.29	0.83	2.90
	(0.35)	(0.28)	(0.24)	(0.30)	(0.68)
Standard deviation of π^*	0.66%	1.53%	0.50%	1.59%	0.44%
	(0.04)	(0.10)	(0.03)	(0.10)	(0.03)
Serial correlation of π^*	0.06	0.19	−0.34	0.16	−0.37
	(0.14)	(0.11)	(0.07)	(0.14)	(0.09)
1-year cumulative π^*	0.61	0.71	0.75	−0.18	0.45
	(0.28)	(0.43)	(0.12)	(0.80)	(0.20)

IRFs of Prices and Reset Prices, All and Sticky Items









Comparison With Smets-Wouters

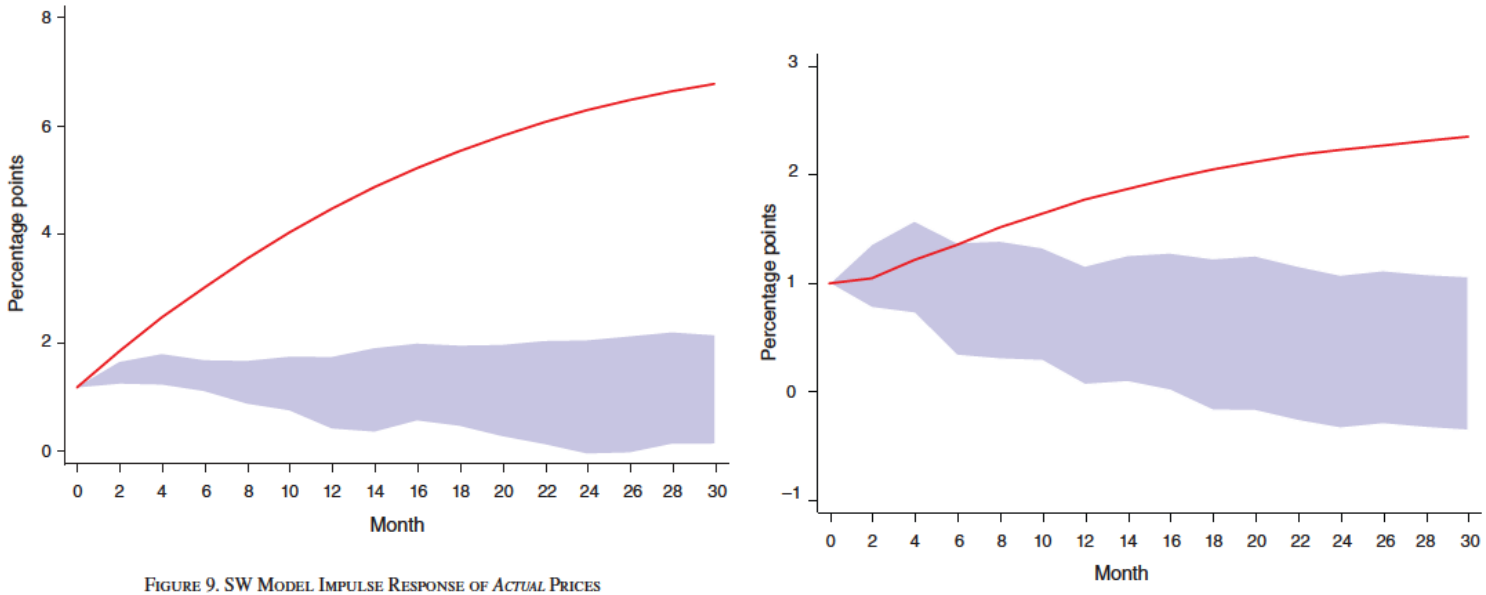


FIGURE 9. SW MODEL IMPULSE RESPONSE OF *ACTUAL* PRICES

- Strong critique of strategic complementarity.
- Paper in some sense is also about inflation not being so persistent in micro data.

Simmons (2021): Store-Level Kinked Demand

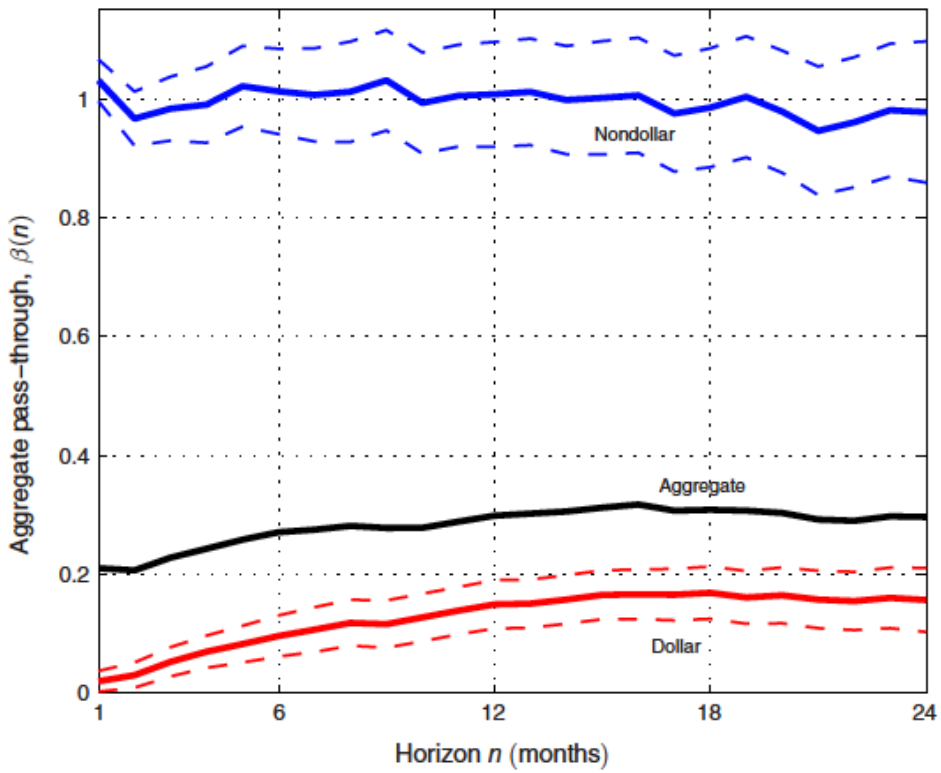
- Joe Simmons (BU Ph.D. student) seeks to resuscitate kinked demand by arguing real rigidity is a store level not item level.
  - Builds on IO literature that customers leaving store makes goods price complements
  - Intuition: Stores want to stabilize customer baskets, not the prices of individual goods so can have large good price changes if baskets are sticky.
- Model: Kimball over basket of two goods
  - Calibrates basket-level super-elasticity to volatility of basket prices
  - Deals with two goods by allowing flexible covariance and targeting covariance between items and baskets
  - Finds super-elasticity of 7.6, implying store-level kinked demand real rigidity amplifies stickiness by factor of 2.5.
  - Calibrated model matches K-W on item-level price changes.

More Direct Evidence On Strategic Complementarities

- Ball and Romer (1990): "While these results show that the necessary amount of real rigidity is large, they do not determine whether this much rigidity is realistic...research has not progressed far enough to produce estimates of...the sharpness in the bend in demand, or of the resulting real rigidity."
- Still roughly the case. Direct evidence on real rigidity is a frontier question.
- Much of the best evidence on real rigidity is international.
  - Use exchange rate shocks to directly measure shocks to MC.
  - Measure pass-through of these exchange rate shocks into "at the dock" prices.

Gopinath, Itskhoki and Rigobon (2010)

- Non-dollar-priced imports adjust nearly one-to-one with exchange rates (price unchanged).
- For dollar-priced imports, only .25% of 1% change in exchange rate since last price change is passed through.
  - Response grows over time.



Gopinath and Itskhoki (2010, QJE; 2010, Macro Annual)

- QJE: Long-Run Pass-Through and Frequency of Adjustment
  - Higher frequency of adjustment $\Rightarrow$ larger long-run pass-through (long horizon even after adjust).
  - Theory: Long-run pass-through determined by factors that affect curvature of profit function, and thus frequency.
  - Support for Π_{11}-based theories.
- Macro Annual: "In Search of Real Rigidities"
  - Prices of imported goods respond to changes in exchange rate from before product's previous price change.
  - Response stronger for trade-weighted exchange rate (agg shock) than bilateral exchange rate (idiosyncratic shock).
  - Competitor prices have a positive effect on price.

GI (2010, Macro Annual): Reset Price Inflation

- Gopinath and Itskhoki also compare their findings to Bils, Klenow, and Malin's.
  - Compute reset price inflation in imports data. Get low persistence (0.04) as in BKM.
  - But when condition on exchange rate, get AR(1) coefficient of 0.33, consistent with gradual build up of reset price inflation and strategic complementarities.
- Suggests that multiple shocks or different degrees of persistence across goods drive inflation.
  - Unconditional reset price inflation emphasized by BKM may not be best test.

Amiti, Itskhoki, and Konings (2019)

- Estimate strategic complementarities γ_{it} from:

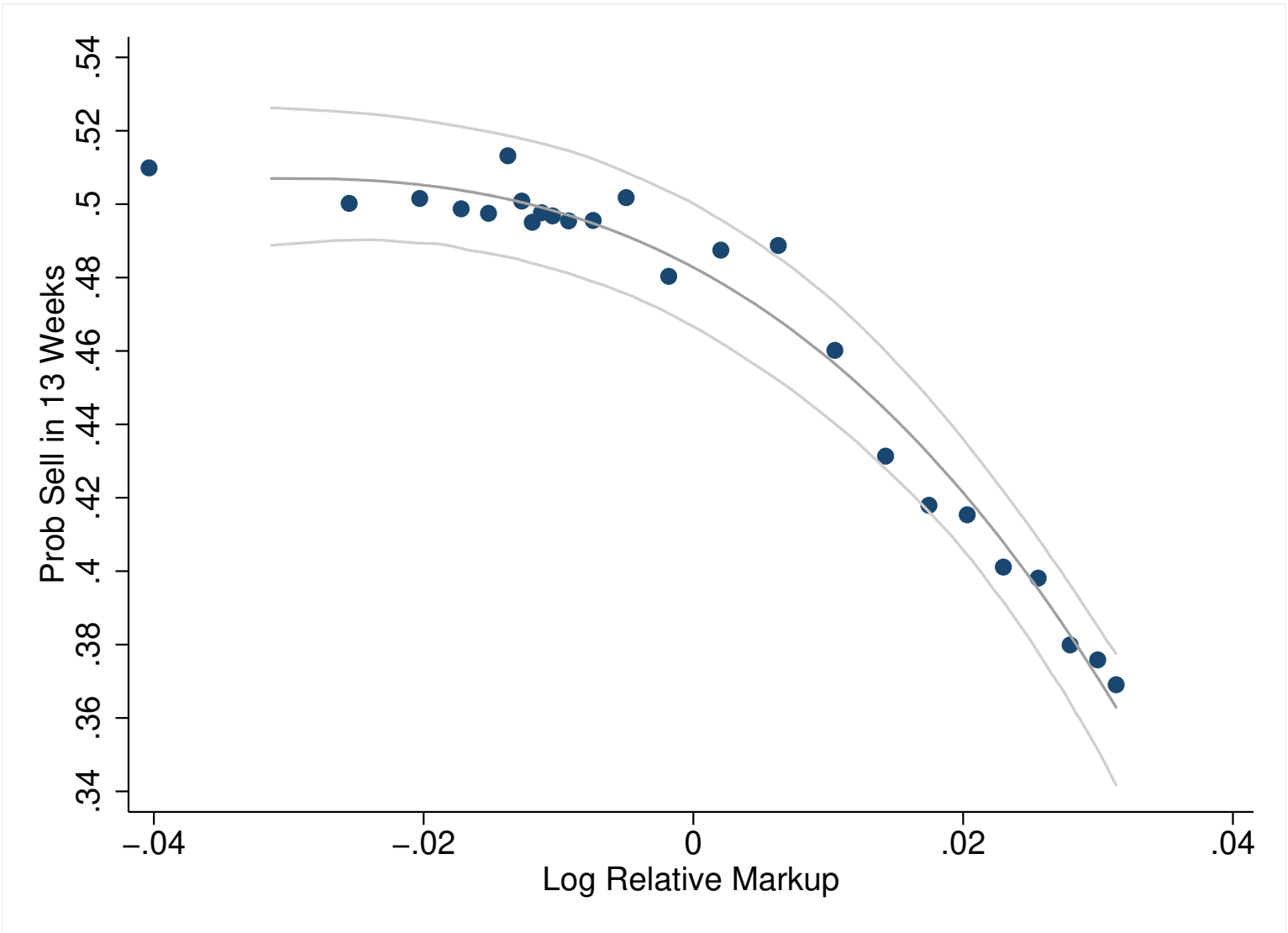
$$\Delta p_{it} = \psi_{it} \Delta mc_{it} + \gamma_{it} \Delta p_{-it} + \varepsilon_{it}$$

- Difficulties: p_{-it} endogenous, mc_{it} is noisy.
- Identification:
  - Use unique Belgian manufacturing and import-export data with prices, competitor prices, and variable costs.
  - Instrument mc_{it} and p_{-it} using differential sourcing of intermediate inputs of various firms and competitors interacted with movements in prices by input and source country.
- Findings:
  - $\psi_{it} = 0.6$, $\gamma_{it} = 0.4$. Significant strategic complementarity.
  - Small firms: $\psi = 1$, $\gamma = 0$. Large firms: $\psi = 0.5$, $\psi = 0.5$.

Guren (2018): Price Stickiness in Housing

- Guren (2018) proposes that concave demand helps explain "momentum" – autocorrelation of price changes – in housing markets.
  - Frictions that have been proposed fall well short of explaining 2-3 years of momentum.
- Idea: No seller wants to set a list price that "sticks out" from comparable houses.
  - Too high, sits on market.
  - Too low, will not sell more quickly, but will garner lower price.
  - Sellers who cannot coordinate find it costly to move price too far from average, amplifying frictions that create momentum.
- Paper provides:
  1. Direct, identified micro evidence.
     - Non-linear IV procedure to estimate curvature of demand accounting for unobserved quality.
     - First direct micro evidence for concave demand.
  2. Show using model that amplification is by a factor of 2-3.

Guren (2018): Price Stickiness in Housing



Summing Up

- Gopinath and Itskhoki (2010) summarize the literature on real rigidities.
  - Most evidence of real rigidities is at the wholesale level (e.g. "at the dock" import prices), not the retail level.
  - They argue this makes sense: retail is more monopolistically competitive, wholesale more oligopolistic.
- Still an unsettled literature.
  - Solid evidence on real rigidity is the frontier of pricing research.
  - Difficult because requires very good data, creativity.

Other Open Questions

- Want to leave you with the other big open questions in the price stickiness literature beyond real rigidity.

1. Inflation Persistence
   - Menu cost models are about sticky prices.
   - But in the data *inflation* is persistent, not the price level.
     - Hump shaped impulse responses for inflation.
   - How to link evidence and models to inflation persistence?
   - Need only small backward-looking component in NKPC.
2. The New Keynesian Phillips Curve: What Are The Shocks?
   - When fit NKPC to data, large role for "markup shocks" (*e.g.*, Smets and Wouters).
   - In other words, residual to the theory explains most of variation in inflation. What are these shocks?
   - Unsatisfying that our theory of output and inflation does a bad job explaining inflation!

BONUS MATERIAL FROM THE CUTTING ROOM FLOOR

Mongey (2018): Market Structure

- Mongey (2018) argues that replacing monopolistic competition with a continuum of oligopolies also provides real rigidity that avoids the Klenow and Willis (2016) critique.
- Callibration strategy similar to Golosov-Lucas.
- Mongey main findings:
  1. Monetary non-neutrality is 2.5$\times$ larger under duopoly.
  2. Smaller menu costs are needed
  3. Can get real rigidity without large idiosyncratic shocks.
  4. Welfare implications are different.
     - Firms sustain higher markups than frictionless model.
     - First order welfare losses, relative to only second order losses from dispersion under monopolistic competition.

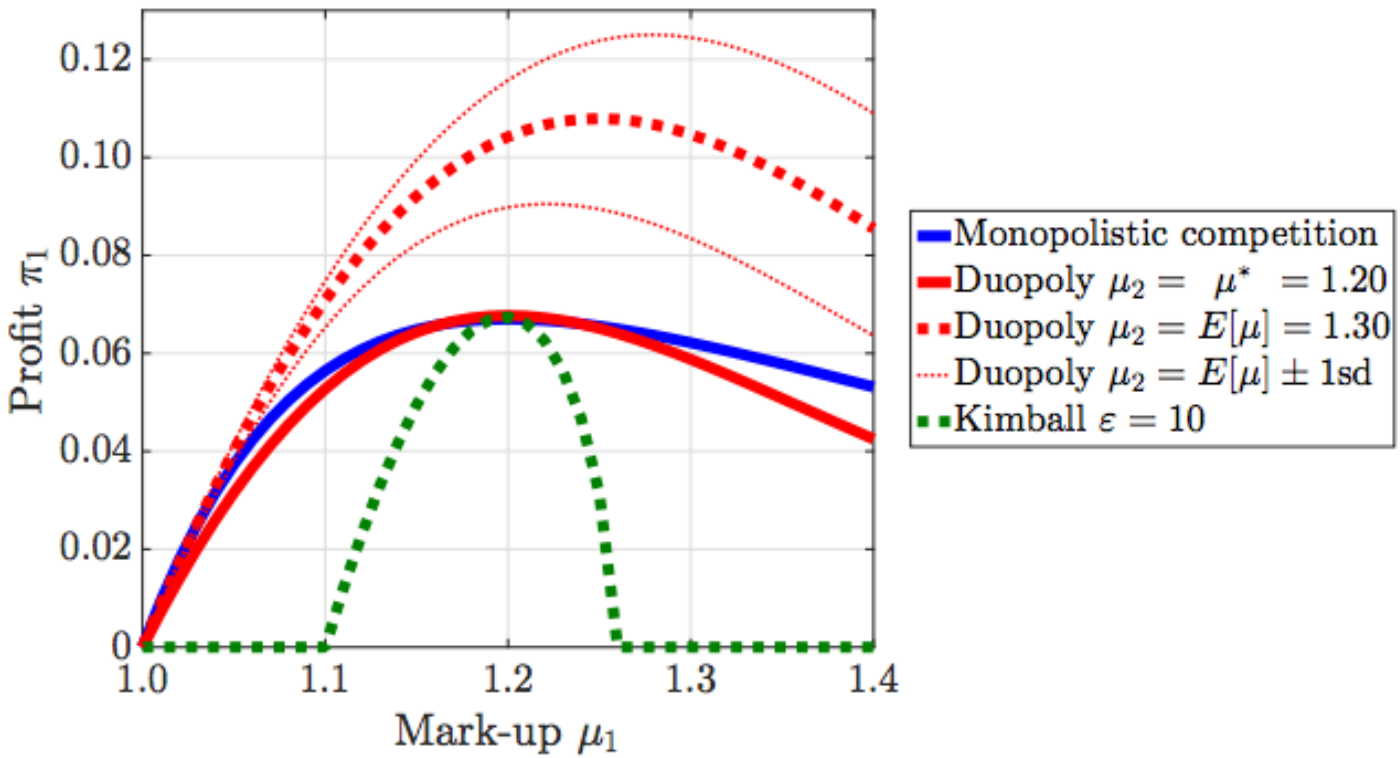
Mongey (2018): Market Structure

		Duopoly	MC	MC′
A. Parameter				
Elasticity of demand	η	10.5	4.5	10.5
Size of menu cost	$\bar{\xi}$	0.17	0.21	0.17
Size of idiosyncratic shocks	σ_z	0.04	0.04	0.04
B. Moments matched				
Average markup	$\mathbb{E}[\mu_{it}]$	1.30	1.30	1.12
Frequency of price change		0.13	0.13	0.19
Ave. absolute size of price change		0.10	0.10	0.05
C. Results				
Std. deviation consumption	$std[c_t]$	0.31	0.13	0.06
Average - Frictionless markup	$\mathbb{E}[\mu_{it}] - \mu_f$	0.10	0.02	0.01

- MC' = not re-calibrating model to match moments.
- Things to noice:
  1. 2.5× larger output fluctuations
  2. 10 ppt higher markups than frictionless economy.
  3. Same size shocks and 25 percent smaller menu costs.

Mongey (2018): Market Structure

- Why does duopoly avoid Klenow and Willis?
  - Rather than increasing curvature of profit function, it shifts in and down when competitor price falls.
  - Inflation $\Rightarrow$ own markup falls, but competitor's markup also falls $\Rightarrow$ optimal price falls, adjust less.
  - With large idiosyncratic cost shock, still adjust.



Kryvtsov and Midrigan (2013): Inventories

- If could observe marginal cost, could distinguish sources of real rigidity in which marginal cost move sluggishly (e.g. Basu) from sources that predict countercyclical markups.
- Kryvtsov and Midrigan (2013) use inventory behavior to back out whether markup or marginal cost is sluggish.
  - Idea: With demand uncertainty, when markups decline should cut inventories because less valuable.
- In data, inventories react less to monetary shock than sales.
- Favors countercyclical markups, as to mach fact:
  1. MC must rise immediately to avoid incentives to purchase inventories while costs are low for coming boom.
  2. Markups must fall to avoid incentives to increase inventory when interest rates are low.

Nakamura and Zerom (2010): Estimating Super Elasticity

- Studies exchange rate pass-through in coffee industry.
  - 1% exchange rate movements $\Rightarrow$ 1/3% price change over six quarters, most after one quarter.
  - Rigidity entirely at wholesale level.
- Structural IO model (BLP) to estimate super-elasticity:
  - Estimate a positive super-elasticity: 1% increase in prices leads to 4.64% increase in elasticity of demand.
  - 59% reduction in pass-through because some costs are local, so exchange rate only partially moves MC.
  - Additional 33% through markup due to kinked demand.
- Consistent with menu cost model.
  - Strategic complementarities play smaller role than one might expect because of coordination in timing of price adjustments around times of large movements in commodity costs.