Micro-Macro Moments: Time- vs. State-Dependent Pricing

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[1]The views expressed herein are solely those of the authors and do not necessarily reflect the views of the Federal Reserve Bank of Cleveland or the Federal Reserve System.

Motivation: Key Question

- The use of micro data has become the new standard in macro.
- Facilitated by:
  - Theoretical advances in heterogeneous agent/production modeling
  - Availability of new, detailed micro datasets
- Typical Approach: Take a rich, micro-founded model $\rightarrow$ calibrate it to micro moments $\rightarrow$ study counterfactuals in the model.
- **Question:** Is there a systematic approach which provides guidance on how to pick moments, and discriminate among models?
  - Micro-macro moments: Response of key macro variables conditional on micro moments to an identified shock of interest

Motivation: Monetary Non-Neutrality

- Demonstrate our approach with a well worked out example, studying the nexus of price-setting and monetary non-neutrality
  - What pricing moments should we care about?
  - Model discrimination: Time- vs. state-dependent pricing models
- Long-standing question in macroeconomics: What price-setting assumptions are key to the transmission of monetary policy?
  - Small changes in modeling assumptions may have dramatically different implications for real effects
  - Major fault line: State (menu cost) vs. time (Calvo) dependent pricing

Motivation: Monetary Non-Neutrality

- Recent emphasis on sufficient statistics
  - Alvarez et al. (AER'16), Dotsey and Wolman (2019), Baley and Blanco (2019)
- Recent questioning of identification in macro
  - Nakamura & Steinsson (JEP '18)
- Contribution of our approach: Compare models *conditional* on policy shocks of interest to macro-variable of interest
  - Consider small and specific shock in normal times.
  - Contrast: Low external validity of studying model selection based on particular, exceptional episodes – *unconditional* of shocks.
    - Gagnon (QJE '09); Nakamura et al. (QJE '18); Karadi & Reiff (AEJMacro '18); Alvarez et al. (QJE '19)

This paper

- Micro-macro moments show:
  - Higher frequency means more responsiveness of prices
  - Higher kurtosis means nothing
  - Reject sufficient pricing statistics in Alvarez et al. (AER 2016)
- Calvo model can accomodate these results. Conventional menu cost does not.
- Two-step methodology to systematically discriminate among models by using micro-macro moments to discipline model choice
  - Key insight: Pure macro-IRF matching may hide non-linearities in the macro variable conditional on micro moments in response to shocks

What Pricing Moments Should We Care About?

One proposal:

> *"We analytically solve a menu cost model that encompasses several models [. . .] The model accounts for the positive excess kurtosis of the size-distribution of price changes [. . .] We show that the ratio of kurtosis to the frequency of price changes is a sufficient statistics for the real effects of monetary shocks [. . .]"*
> *"We [. . .] conclude that a model that successfully matches the micro evidence produces persistent real effects that are about 4 times larger than the Golosov-Lucas model, about 30% below the effect of the Calvo model [. . .]"*

Alvarez, Le Bihan, Lippi (AER, 2016)

Pricing Moment - Sufficient Statistic

Setup and main result in Alvarez, Le Bihan, Lippi (2016):

- Economy of multiproduct firms
- Second-order, continuous time approximation of profits
- Economies of scope in price-setting, free price changes
- No strategic complementarities, normal shocks, no trend inflation
- Aggregation following small, one-time monetary shock δ, ignoring GE effects

- **Sufficient statistic:**

$$\mathrm{M} = \frac{\delta}{6\epsilon} \frac{Kur(\Delta p_i)}{N(\Delta p_i)} \tag{1}$$

where $\frac{1}{\epsilon}$ is the supply elasticity of labor to the real wage, and δ a small, one-time monetary shock.

- Intuition: Kurtosis embodies small changes and low selection effect.

Demonstrating the approach

- Step 1: Constructing micro-macro moments using conditional price IRFs following a monetary shock
- Step 2: Comparing empirical to theoretical IRFs from a multi-sector model to discriminate models

Step 1: Slicing the Data

- Calculate sectoral pricing moments from BLS producer price (PPI) micro data
  - Time horizon: 1998-2005
  - 154 sectors at 6-digit NAICS
  - Frequency, kurtosis, average size, and fraction small price changes
  - First pool data at sectoral level and compute monthly statistics, then average across months
- Two subsets of data, 1 above and 1 below median, to calculate empirical IRF for each group
- Summary statistics:

	Median Value	Below Median Average	Above Median Average
Frequency	0.20	0.14	0.35
Kurtosis	5.5	4.0	9.0
$\frac{\text{Kurtosis}}{\text{Frequency}}$	27.2	15.7	45.0
N	154	77	77

Table: Pricing Moment Slices

Step 1 (Continued): Construct Price IRF

- Construct (potentially) differential price response to monetary shock
- Two methods:
  - FAVAR (BBE 2005, BGM 2009)
  - Narrative approach (R&R 2004)
- FAVAR uses data rich environment
- Model free narrative approach
- Examine empirical price IRF response of two subsets of data

Empirical IRF - FAVAR Approach (BGM 2009)

- Assume economy is affected by vector C_t of common components

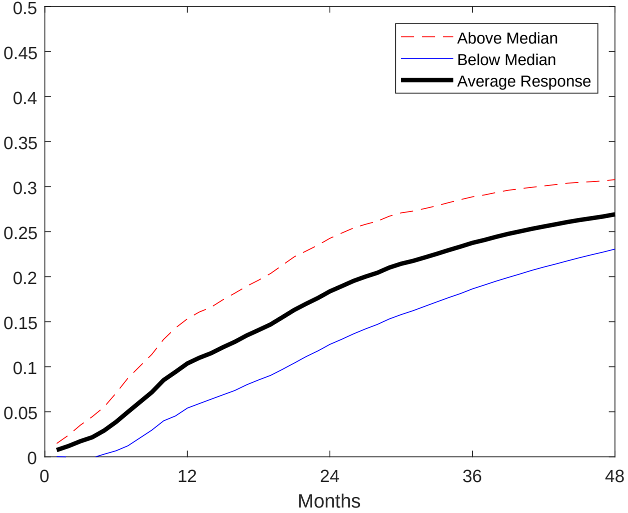
$$C_t = \Phi(L) C_{t-1} + \nu_t \tag{2}$$

  - Where $C_t = [F_t \; R_t]'$ and F_t are a small number K of common factors
- Common factors link to large set of observable series X_t

$$X_t = \Lambda C_t + e_t \tag{3}$$

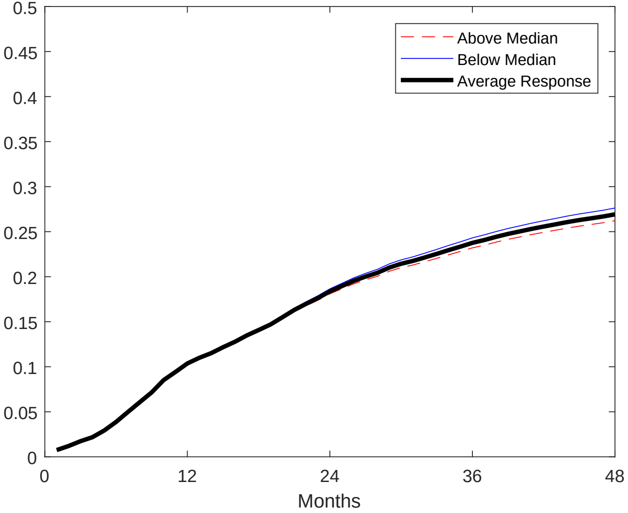
- Monthly data for 653 monthly series 1976.1-2005.6
- 154 PPI price series
- Calculate sector-specific IRF, then use average response

IRF Results - FAVAR - Frequency



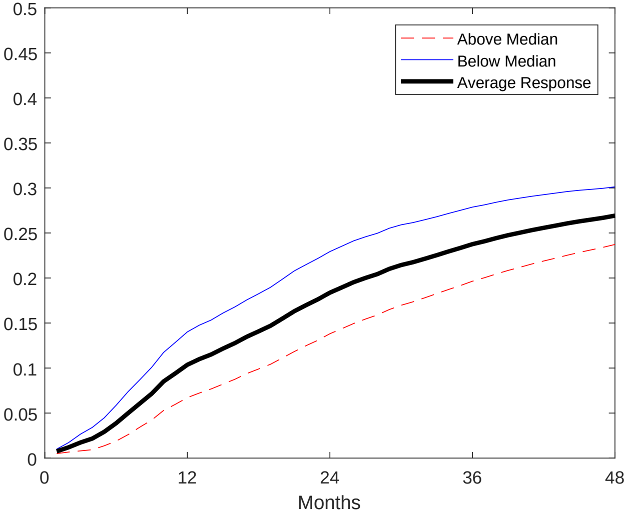
- High frequency of price changes: large price response.

IRF Results - FAVAR - Kurtosis



- Kurtosis of price changes: equal price response.

IRF Results - FAVAR - Kurtosis/Frequency



- High kurtosis over frequency price changes: low price response.

Robustness

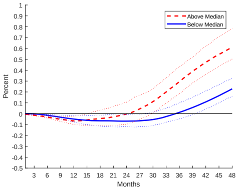
Empirical IRF - Narrative Approach (R&R 2004)

- Narrative approach
  - Constructed using Greenbook forecasts
  - Regresses change in FFR around FOMC on lag of FFR and Fed's information set
  - Purging monetary shock series of forecastable variation
  - Narrative series free from endogenous and anticipatory actions
- Run baseline regression

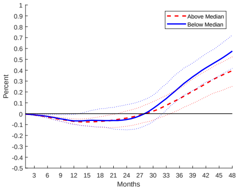
$$\pi_t^c = \alpha^c + \sum_{k=1}^{11} \beta_k^c D_k + \sum_{k=1}^{24} \eta_k^c \pi_{t-k}^c + \sum_{k=1}^{48} \theta_k^c MP_{t-k} + \epsilon_t \qquad (4)$$

- Monthly data from 1976.1-2005.6
- 154 PPI data series
- Calculate average inflation IRF for the above and below median statistic subsets

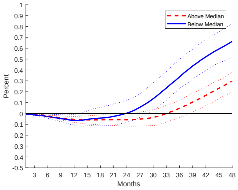
IRF Results - Narrative Approach



Frequency



Kurtosis



Kurtosis/Frequency

- Same results using Romer and Romer shocks
  - High frequency of price changes: larger price response
  - No relationship between price response and kurtosis of price change
  - Smaller price response in the cross section for high kurtosis over frequency sectors

Robustness: Firm-Level Sales Evidence

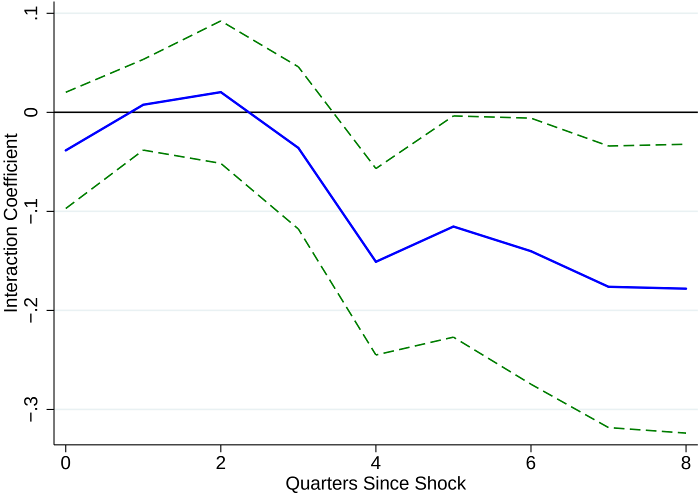
- Calculate pricing moments at firm level to help us control for additional factors
  - Pricing moments calculated for 2005-2014
  - Merge pricing characteristics with quarterly Compustat data (N=550 representative firms)
- Identify monetary shocks using high frequency Fed Funds rate shocks

$$\epsilon_t^m = \frac{D}{D-t}\left(ff_{t+\Delta^+} - ff_{t-\Delta^-}\right) \tag{5}$$

- Data from 1989Q2-2008Q2
- Sum up shocks within each quarter
- Study differential sales response across firms based on pricing statistics following monetary surprise:

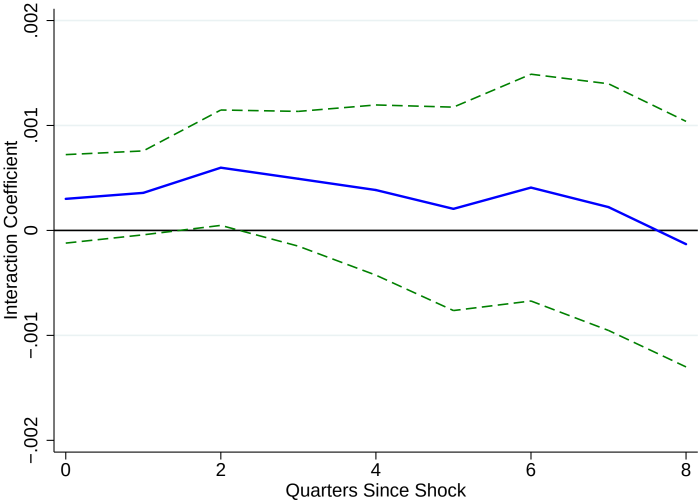
$$\Delta log(sales)_{j,t+h} = \alpha_t + \alpha_j + \beta_h PS_j \epsilon_t^m + \eta_{j,t+h} \tag{6}$$

Firm-Level Results - FF Approach - Frequency



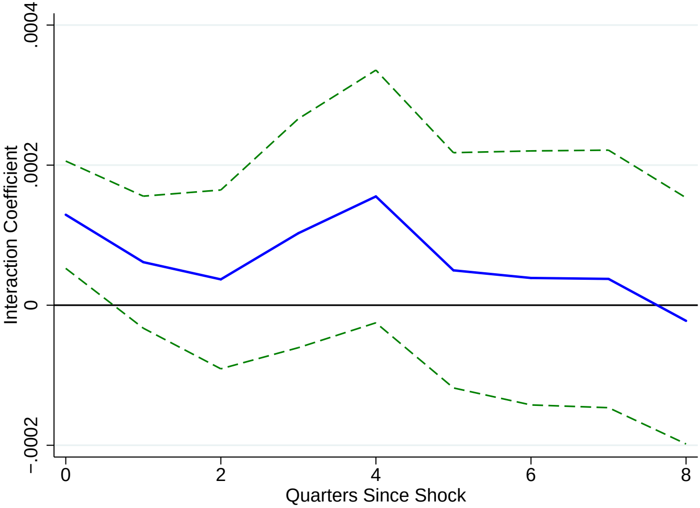
- Firms with high frequency have lower sales growth following expansionary shock

Firm-Level Results - FF Approach - Kurtosis



- Kurtosis of price change does not have differential sales effect

Firm-Level Results - FF Approach - Kurtosis/Frequency



- Kurtosis over frequency has effect on impact for sales growth

New Pricing Facts

- Separating disaggregated sectors by pricing moments we find:
  - Lower frequency of price change leads to larger consumption response
  - Kurtosis of price changes does not affect consumption response "irrelevance of kurtosis"
  - Higher kurtosis over frequency leads to larger consumption response
    - But: only due to role of frequency of price changes
- Results robust to measurement of monetary shock

Step 2: Model Discrimination

- Construct general equilibrium multi-sector pricing model that embeds both menu cost and Calvo models
- Calibrate models to match two subsets of sectors
  - Sectors above and below median pricing moments
- Can each model and calibration replicate ordering of empirical IRFs?

Multi-Sector Model

- Standard household side of model (log consumption, linear labor)
- Monopolistically competitive firms i set prices to maximize future expected profit subject to sticky price constraint
- Firms produce output subject to aggregate and idiosyncratic shock:

$$y_t(i) = A_t z_t(i) L_t(i) \tag{7}$$

- After choosing price, firms fulfill total demand of good i

$$y_t(i) = Y_t \left(\frac{p_t(i)}{P_t} \right)^{-\theta} \tag{8}$$

Firm Pricing

- Firms choose price to maximize future expected profit, with period-profit function

$$\pi_t(i) = p_t(i)y_t(i) - W_t L_t(i) - \chi_j(i) W_t I_t(i) \tag{9}$$

where j denotes firms

- Model embeds both menu cost and Calvo models
- Menu costs follow

$$\chi_j(i) = \begin{cases} 0 & \text{with probability } \alpha_j \\ \chi_j & \text{with probability } 1 - \alpha_j, \end{cases} \tag{10}$$

- Set $\chi_j = \infty$ for Calvo model

Firm Productivity

- Firm productivity follows mean-reverting, leptokurtic shock process

$$logz_t(i) = \begin{cases} \rho_z logz_{t-1}(i) + \sigma_{z,j}\epsilon_t(i) & \text{with probability } p_{z,j} \\ logz_{t-1}(i) & \text{with probability } 1 - p_{z,j} \end{cases}$$

- Aggregate productivity follows AR(1) process

$$logA_t = \rho_A logA_{t-1} + \sigma_A \nu_t \tag{11}$$

- Close the model with a nominal aggregate spending process

$$logS_t = \mu + logS_{t-1} + \sigma_s \eta_t \tag{12}$$

Pricing Moments - Frequency Split

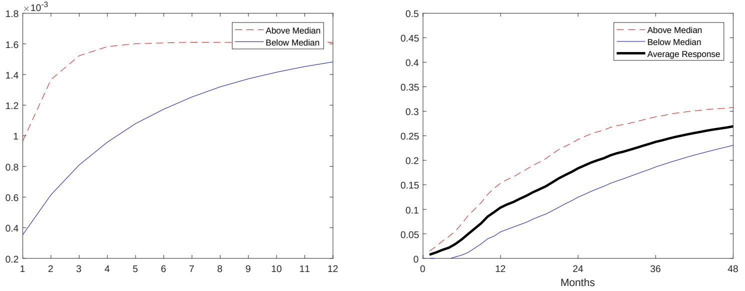
- Calibrate sectoral parameters to match sector specific pricing moments, common parameters the same

Frequency Calibration

	Low Frequency Sector			High Frequency Sector		
Moment	Data	MC	Calvo	Data	MC	Calvo
Frequency	0.14	0.14	0.14	0.35	0.35	0.33
Average Size	0.073	0.074	0.073	0.062	0.061	0.062
Fraction Small	0.46	0.32	0.33	0.31	0.42	0.47
Kurtosis	6.2	6.1	6.3	6.7	6.7	6.7
$\frac{\text{Kurtosis}}{\text{Frequency}}$	44.8	42.8	46.2	19.3	18.8	20.1

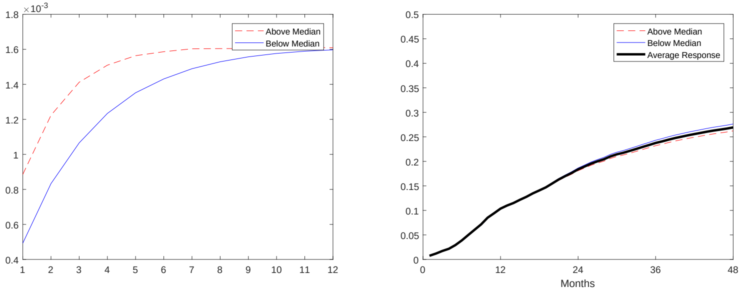
Calibration Values Kurtosis Kurtosis/Frequency

Multi-Sector Menu Cost Results - Frequency Split



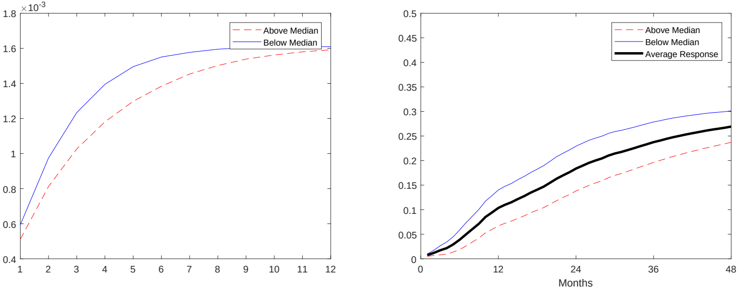
- Menu cost model can match ordering of frequency IRFs

Multi-Sector Menu Cost Results - Kurtosis Split



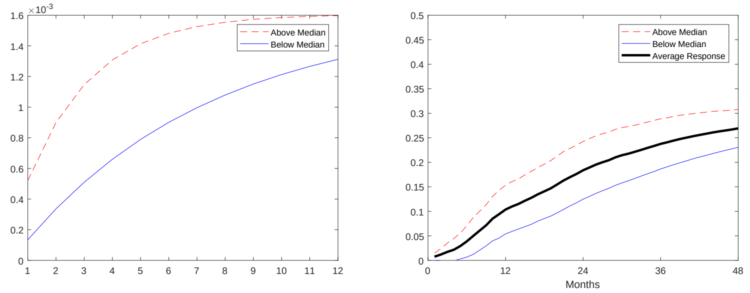
- Menu cost model misses irrelevance of kurtosis IRFs

Multi-Sector Menu Cost Results - Kurtosis/Frequency Split



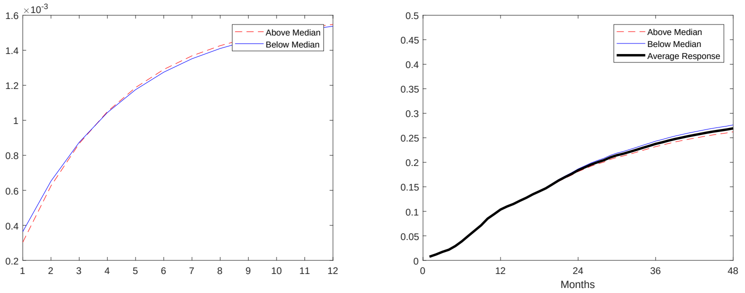
- Menu cost model matches ordering of kurtosis/frequency IRFs

Multi-Sector Calvo Results - Frequency Split



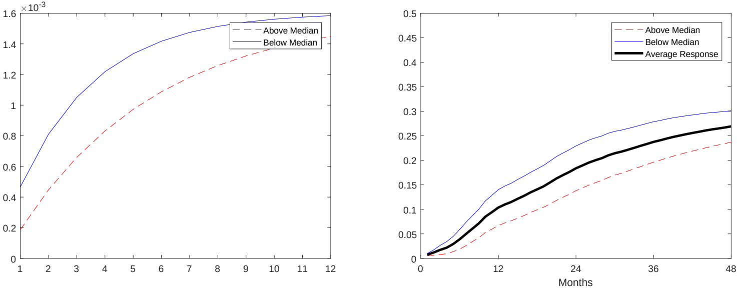
- Calvo model matches ordering of frequency IRFs

Multi-Sector Calvo Results - Kurtosis Split



- Calvo model matches ordering of kurtosis IRFs

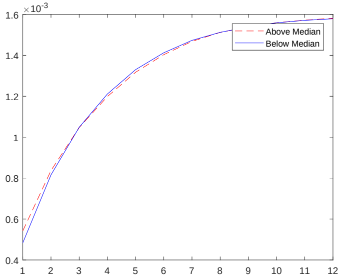
Multi-Sector Calvo Results - Kurtosis/Frequency Split

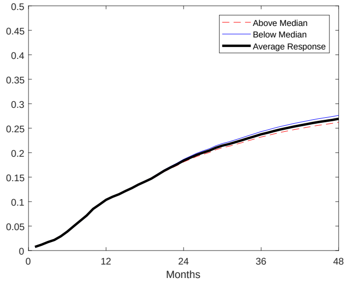


- Calvo model matches ordering of kurtosis/frequency IRFs

Comparative Static Exercise

- Menu cost model consistent with micro-pricing behavior is inconsistent with empirical macro IRFs
- Vary one parameter at a time, starting from kurtosis split parameterization, to recover irrelevance of kurtosis
- Minimum found when menu cost of high kurtosis sector is increased: $\Rightarrow$we recover irrelevance of kurtosis for aggregate price response





Menu Cost - Kurtosis Irrelevance - Missing Moments

Kurtosis Calibration						
	Low Kurtosis Sector			High Kurtosis Sector		
Moment	Data	Baseline	Comp Static	Data	Baseline	Comp Static
Frequency	0.24	0.24	0.24	0.25	0.25	0.20
Average Size	0.072	0.071	0.071	0.063	0.070	0.084
Fraction Small	0.35	0.35	0.34	0.42	0.44	0.35
Kurtosis	4.0	4.0	4.0	9.0	8.2	6.4
$\frac{\text{Kurtosis}}{\text{Frequency}}$	17.0	16.9	16.8	36.0	32.3	32.3

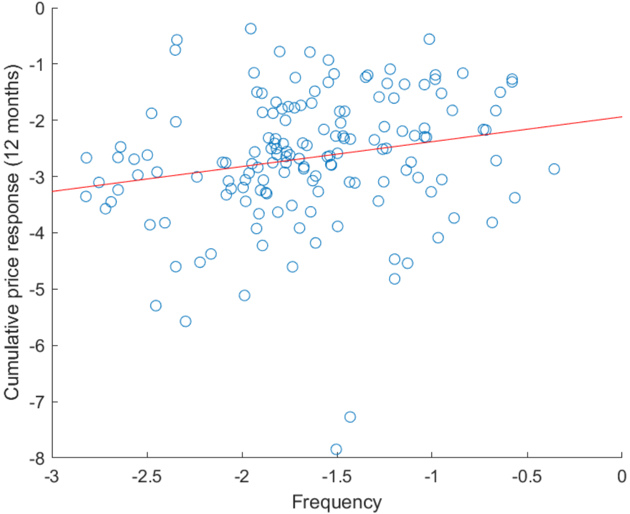
Missing micro pricing moments for the high kurtosis sector:

1. frequency and size of price changes
2. kurtosis

Conclusion

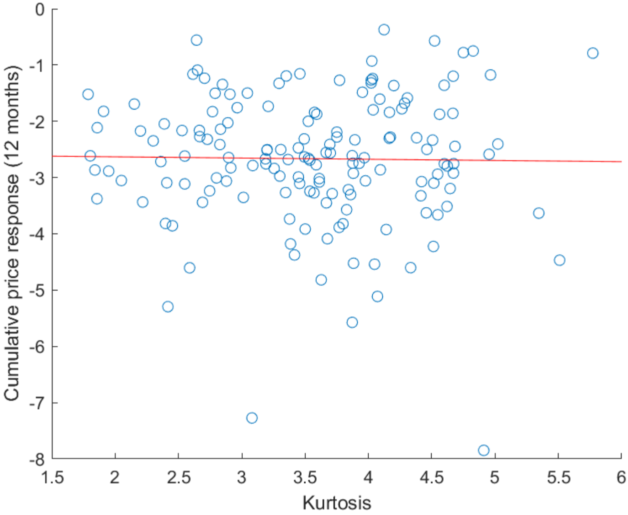
- Propose new way to discriminate among macro models
  - Matching micro-moments is not informative enough:
    Tie micro moments, especially sufficient statistics, to macro moments to discipline model choice
  - Non-parametric, model-free source of identification
- Apply method to price-setting and monetary non-neutrality:
  - Kurtosis of price changes is not a sufficient statistic for monetary non-neutrality
  - Kurtosis over frequency of price changes is sufficient only due to sufficiency of frequency
  - Menu cost model is not consistent with micro moments and aggregate impulse results, given kurtosis split of the micro data

FAVAR Robustness - Frequency



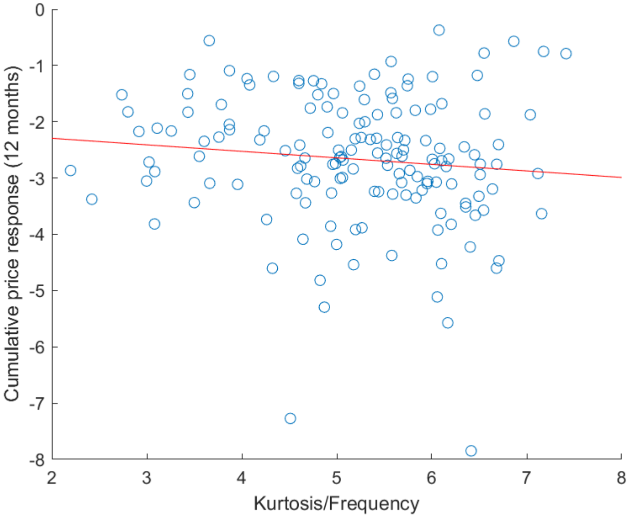
- Larger price response in the cross section for high frequency sectors.

FAVAR Robustness - Kurtosis



- No relationship between price response and kurtosis of price change.

FAVAR Robustness - Kurtosis/Frequency



- Smaller price response in the cross section for high kurtosis over frequency sectors.

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Calibration - Frequency Split

- Parameters common to all sectors calibrated the same for all exercises
  - Discount rate, nominal shock process, aggregate TFP, elasticity of substitution
- Second set of parameters calibrated to match sector-specific pricing moments

Frequency Calibration				
	Low Frequency Sector		High Frequency Sector	
Parameter	MC	Calvo	MC	Calvo
χ_j	0.052	∞	0.00047	∞
$p_{z,j}$	0.073	0.139	0.16	0.244
$\sigma_{z,j}$	0.167	0.15	0.141	0.136
α_j	0.11	0.139	0.22	0.348

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Pricing Moments - Kurtosis Split

Kurtosis Calibration						
	Low Kurtosis Sector			High Kurtosis Sector		
Moment	Data	MC	Calvo	Data	MC	Calvo
Frequency	0.24	0.24	0.23	0.25	0.25	0.24
Average Size	0.072	0.071	0.072	0.063	0.070	0.063
Fraction Small .01	0.35	0.35	0.25	0.42	0.44	0.50
Kurtosis	4.0	4.0	4.1	9.0	8.2	9.0
$\frac{\text{Kurtosis}}{\text{Frequency}}$	17.0	16.9	17.6	36.0	32.3	37.5

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Pricing Moments - Kurtosis/Frequency Split

	Kurtosis/Frequency Calibration					
	Low Kurtosis/Frequency Sector			High Kurtosis/Frequency Sector		
Moment	Data	MC	Calvo	Data	MC	Calvo
Frequency	0.30	0.28	0.28	0.18	0.20	0.17
Average Size	0.067	0.069	0.069	0.068	0.065	0.068
Fraction Small .01	0.32	0.34	0.32	0.45	0.42	0.41
Kurtosis	4.7	4.6	4.6	8.3	8.2	7.7
$\frac{\text{Kurtosis}}{\text{Frequency}}$	15.7	16.3	16.3	45.0	40.0	46.1

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