The extensive and intensive margin of price adjustment to cost shocks: Evidence from Danish multiproduct firms

Luca Dedola (ECB & CEPR), Mark Kristoffersen (FH), Gabriel Zuellig (Oxford & SFI)

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Micro Price Adjustment and Inflation Dynamics

- Does lumpy and heterogeneous price adjustment matter for inflation dynamics, monetary transmission?
  - Auclert, Rigato & Straub 2021: Generalized Phillips Curve = IRF of prices to marginal costs
- "**Extensive**" (prob. of price changes) and "**intensive**" margin (size of price changes):
  - How much time vs state dependence (TD & SD) in decision to change prices? Synchronization in multiproduct firms?
  - "**Selection**": How much interdependence between extensive & intensive margin?

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  - "**Selection**": How much interdependence between extensive & intensive margin?
- Heterogeneity in intensive margin across shocks, sectors and firms ("real rigidities"):
  - Firm-specific vs more common shocks (Boivin et al. 2009)?
  - Supply chain/network effects (Rubbo 2020)?
  - Muted adjustment in larger firms (Amiti et al. 2019)?

What We Do and Main Results

Joint estimation of margins of micro price adjustment to cost shocks

- **Extensive margin**:
  - **State dependence:** Frequency affected by firm (cost), industry and aggregate shocks
  - Only imperfect **synchronization** of price changes within firms
- **Selection and intensive margin**:
  - Despite state-dependence, small **selection effect ("bias")**
  - Price adjustment consistent with hybrid TD-SD models
- **Heterogeneity** across shocks, sectors and firms — real rigidities matter for adjustment:
  - Delayed for energy costs/oil supply shocks, through sectoral "pipeline"
  - Faster but smaller ($<< 1$) for (more) idiosyncratic import cost
  - Smaller adjustment mainly due to larger firms

Selected Literature

- Theory & evidence on price setting in multiproduct firms: Alvarez & Lippi (2014), Bhattarai & Schoenle (2014), Bonomo et al. (2019)
- Carlsson & Skans (2012), Carlsson (2017): State dependence and pass-through of firm-level labor costs
- Karadi, Schoenle & Wursten (2020): Conditional probability of adjustment and selection
- Balleer et al. (2020): Response of frequency and size of price changes to monetary shocks
- Boivin et al. (2009), Smets et al. (2019): Macro price dynamics in response to aggregate and *sectoral* (idiosyncratic) shocks

Roadmap

1. **Two-step empirical approach**
2. Data description and implementation
3. Estimates of extensive and intensive margin

Lumpy Price Adjustment & State Dependence

- With sticky prices adjustment via extensive and intensive margins
  - Important to distinguish stickiness (how many $\Delta p = 0$) and pass-through into "reset" prices ($\Delta p \neq 0$)
  - Under SD, prices farther from desired value more likely to change

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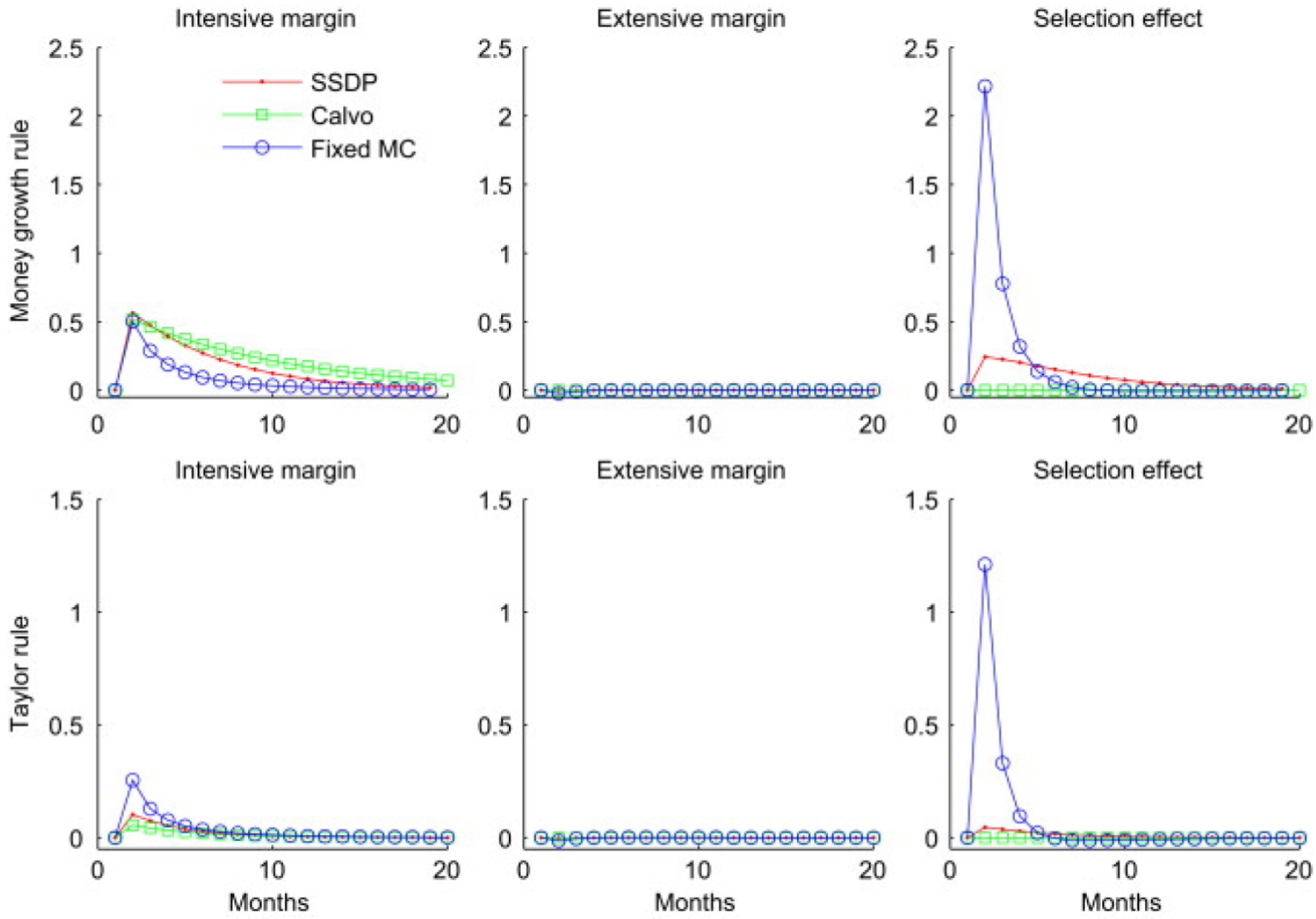
  - Under SD, prices farther from desired value more likely to change
- What happens in response to cost shock δ?
  - Selection: Prices receiving other (idiosyncratic) shocks of same sign as δ more likely to change
  - Selection effect: Average cross-section of actual $\Delta p \neq 0$ larger than $|\delta|$, the higher SD
  - Alvarez & Lippi 2014,20: Selection matters even when cost shock δ small, with minor effect on frequency
    Still adjustment shifts e.g. from large $\Delta p_{it} < 0$ to large $\Delta p_{it} > 0$

Price Adjustment Margins under SD and TD models

- Costain & Nakov 2011



Dealing with Selection Bias due to Unobserved Shocks

- Not a problem if all shocks affecting prices are observable
- Otherwise, OLS regressions estimating pass-through with $\Delta p \neq 0$ may suffer from endogenous selection bias
- To wit: unobserved shocks affect decision to change prices and its size, resulting in omitted variable bias for all costs
- "Heckit" approach: Including correction for selection bias (to capture "spurious" correlation due to omitted variables)

Back-of-the-envelope Estimates of Margins Decomposition

- Caballero & Engel 07 decomposition of overall price change $(\widehat{p}_{t+h} - \widehat{p}_{t-1+h})$ conditional on cost shock (for each horizon h):

$$\widehat{p}_{t+h} - \widehat{p}_{t-1+h} = \underbrace{\overline{\lambda}_h \left(\widehat{p}^*_{t+h} - \widehat{p}^*_{t-1+h}\right)}_{TD\ MARGIN} + \underbrace{\left[\left(\widehat{p}_{t+h} - \widehat{p}_{t-1+h}\right) - \overline{\lambda}_h \left(\widehat{p}^*_{t+h} - \widehat{p}^*_{t-1+h}\right)\right]}_{SD\ MARGIN}$$

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- SD margin $=: \left(\widehat{p}_{t+h} - \widehat{p}_{t-1+h}\right) - \overline{\lambda}_h \left(\widehat{p}^*_{t+h} - \widehat{p}^*_{t-1+h}\right)$ — further decompose in selection proper, change in freq. $\Delta\lambda_{t,h}$

Joint Estimation of Extensive and Intensive Margin, Selection

- Two-step estimation correcting (and testing) for selection, drawing on Bourguignon et al. 2007
- First step: Estimate probability of changing prices as multinomial logit over $\Delta p > 0$,$\Delta p < 0$, $\Delta p = 0$
- Second step: Estimate price adjustment in "reset" prices $\Delta p \neq 0$, with 1st step "bias correction"

Joint Estimation of Extensive and Intensive Margin, Selection

- Polycothomous selection model over horizons $h = 0, ..., H$:

$$r^*_{ij,m,t+h} = \gamma^h_m Z_{ij,t} + \eta_{ij,m,t+h}, \qquad m = -1, 0, 1$$

$$p_{ij,t+h} - p_{ij,t-1+h} = \beta^h X_{ijt} + u_{ijt+h}, \qquad m \neq 0$$

$$E\left(u_j \left| \eta, \gamma Z \right.\right) \neq 0 \ (\textit{selection bias})$$

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- r^* is (latent) firm's "return" over categorical variable m :

$$m = \begin{cases} -1 \text{ if } p_{ij,t+h} - p_{ij,t-1+h} < 0 \\ 1 \text{ if } p_{ij,t+h} - p_{ij,t\ \ 1+h} > 0 \\ 0 \ \textit{otherwise} \end{cases} ;$$

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  - E.g., choose to increase prices if $r^*_1 > \max(r^*_m)$

First Step: Extensive Margin

- Positing η (cross-sectionally) $\sim$iid Gumbel yields multinomial logit for each horizon h (e.g. McFadden 1973):

$$\Pr\left(m_{ij,t+h} = 1, 0, -1 \,|Z_{ijt}\right) = \Phi\left(\gamma_m^h Z_{ijt}\right) = \frac{e^{\gamma_m^h Z_{ijt}}}{1 + \sum_m e^{\gamma_m^h Z_{ijt}}}$$

- Flexible *non-linear* specification: coefficients γ_m^h (and β^h) are specific across outcomes m and horizons h
  - Explanatory variables $Z_{ij,t}$ can have asymmetric effects at any horizon h on the probability of price hikes or cuts
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- Alternatively, assume $\eta \sim$ multivariate normal to get multinomial probit (computationally more challenging)

Second Step: Intensive Margin & Selection Correction

- Under state-dependence 2nd step error "u" not independent of η_m ("spurious" correlation due to selection)
- Dubin-McFadden '84 extension of Heckman '79: Conditional expectations linear function of know convolutions of η_m

$$E\left(u_j \left| \eta, \gamma Z \right.\right) = \mu\left(P_{-1}, P_0, P_1\right)$$

$$p_{ij,t+h} - p_{ij,t-1} = \beta^h X_{ijt} + \underbrace{\lambda^h_{m^*}\mu(\mathrm{Pr}_{h,m^*}) + \sum_{m \neq m^*} \lambda^h_m \left(\mu(\mathrm{Pr}_{h,m}) \frac{\mathrm{Pr}_{h,m}}{(\mathrm{Pr}_{h,m}-1)}\right)}_{\text{selection bias correction}} + w_{ij,t+h},\ m^* \neq 0$$

where $\mu\left(\cdot\right)$ numerical integrals over individual observation probabilities from 1st step logit

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- Test of selection bias: coefficients $\lambda^h_m \neq 0$; *economic size* of bias comparing estimates with/w-o correction term

Roadmap

1. Two-step empirical approach
2. **Data description and implementation**
3. Results on extensive and intensive margin

Data: Prices and Firms

- Monthly goods prices for Danish PPI covering 70+% total sales of industrial production, 1993-2017
- 3500 monthly prices for domestic and export transactions
- 2900 monthly imported input prices
- From 1140 firms (representative sample for prices)
- Median duration of price reporting: 115 months

- Merge with firm-level cost data:

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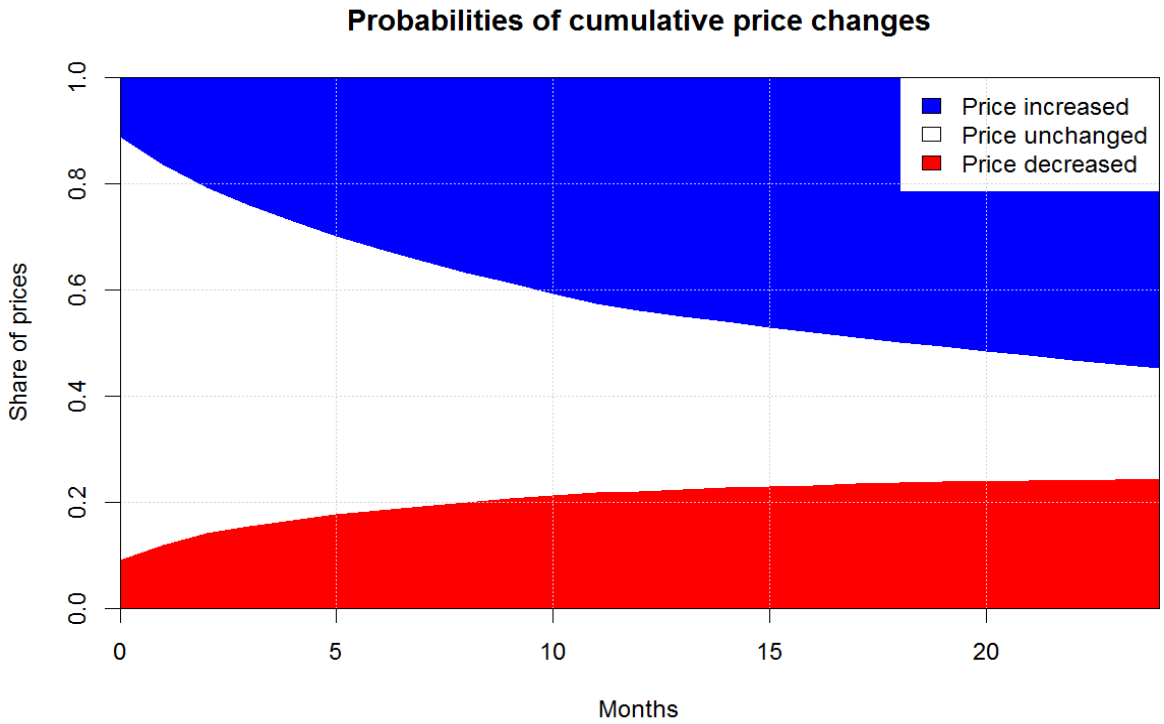
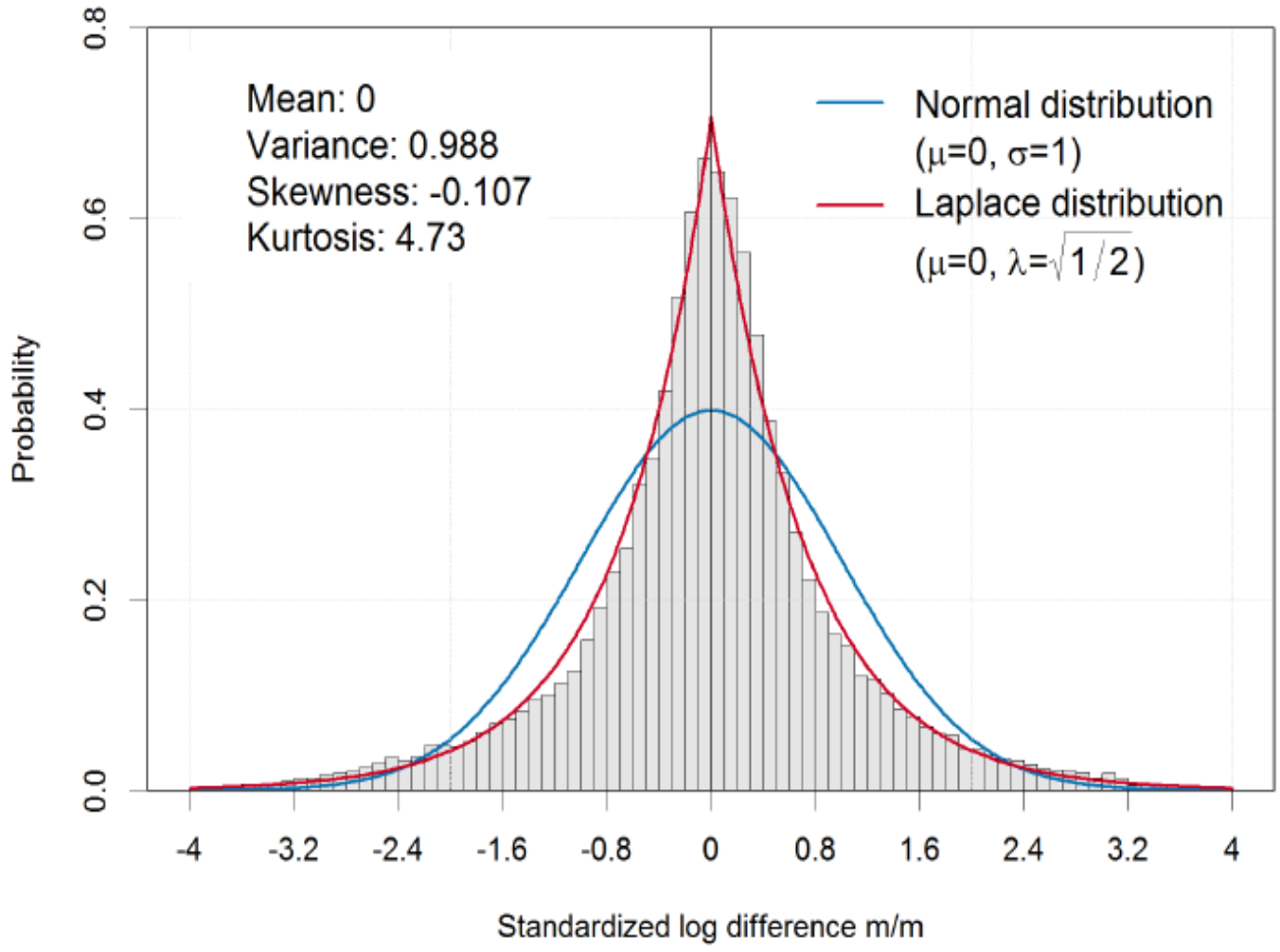
- Merge with firm-level cost data:
  - Accounting data: Annual cost shares, 1994-2016
  - VAT filings: Monthly/quarterly sales & input purchases, 2001-2017
  - Labor costs: Monthly wage bill and hours worked, **2008-2017**

Frequency of (Cumulated) Price Changes << 1



Distribution of Price Changes Has High Kurtosis



Two cost shocks

1st order approximation to marginal costs (Amiti et al. 2019):

- $\phi^E_{j,t-1}\Delta p^E_t$: Energy cost shock ($std = 0.3\%$)
  - Firm share of energy in total cost from balance sheet data (mean 1.8%)
  - Interacted with Baumeister-Hamilton (2019) *structural* oil supply shock (scaled with elasticity of Danish energy price)

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  - Interacted with mean of within-firm import prices from same PPI survey — identification by controlling for other firm costs, variables

Covariates in 1st and 2nd step

- Time-varying controls (plus firm size, #products, monthly and sector dummies):
  - Three-month changes in sales and intermediates purchases
  - Change in hourly wage interacted with firm labor share
  - Product-level mean of competitors' prices $\Delta\overline{p}_{-i,jt}$ (Amiti et al. 2019)
  - Aggregate controls: ΔCPI (ΔPPI), $\Delta NEER$
- Included only in logit (1st step) to enhance 2nd step estimation (usually not included in pass-through regressions):
  - Age of price
  - Within-firm volatility of price changes over past 5 years
  - **Price Synchronization**: Share of *positive* & *negative* price changes within (multiproduct) firms, and among competitors

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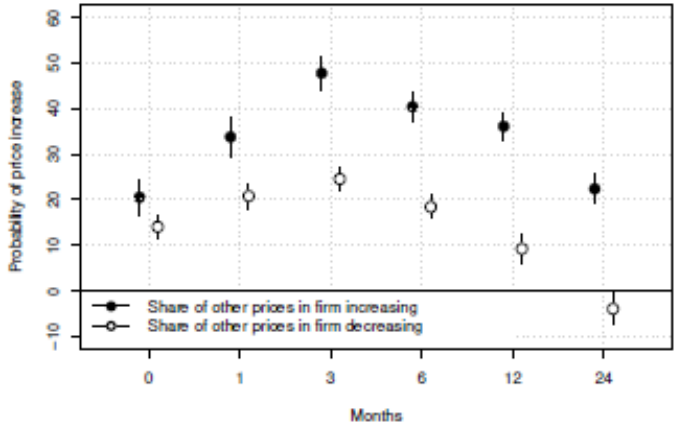
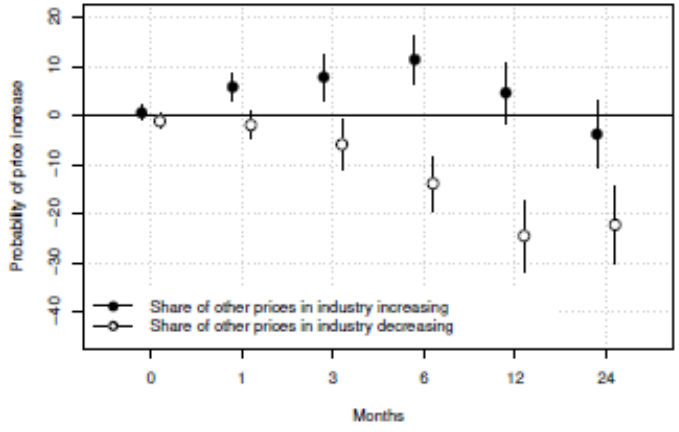
1st Step: Imperfect Synchronization

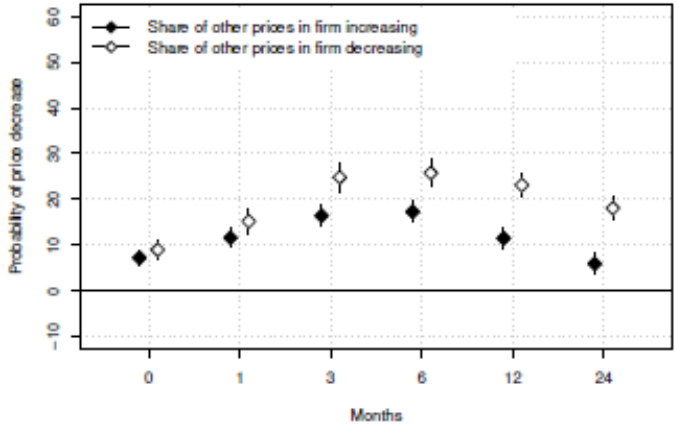
- Within-firm sync. (weakly) rises with #products

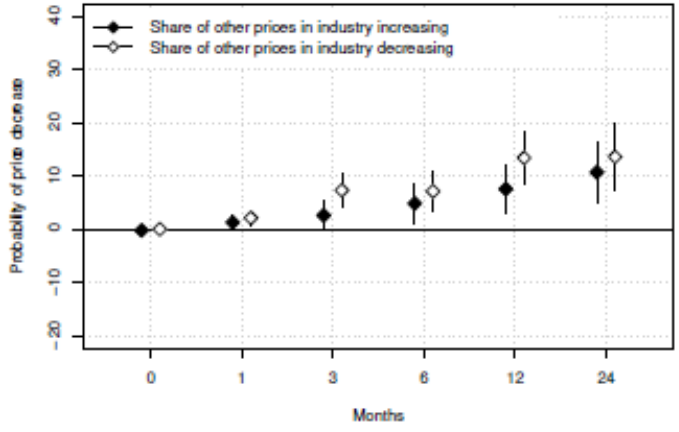
(a) within firm



(b) across firms within industry



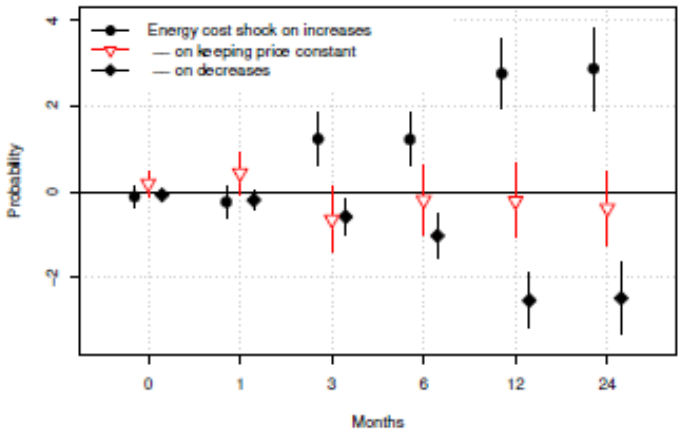




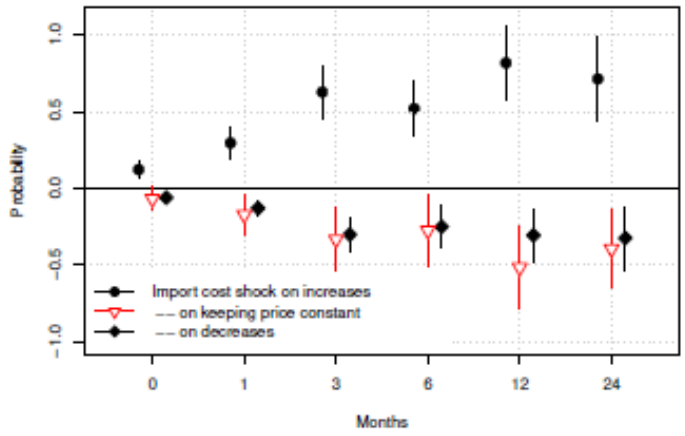
1st Step: Some State Dependence...

- No strong non-linearity even when two shocks combined

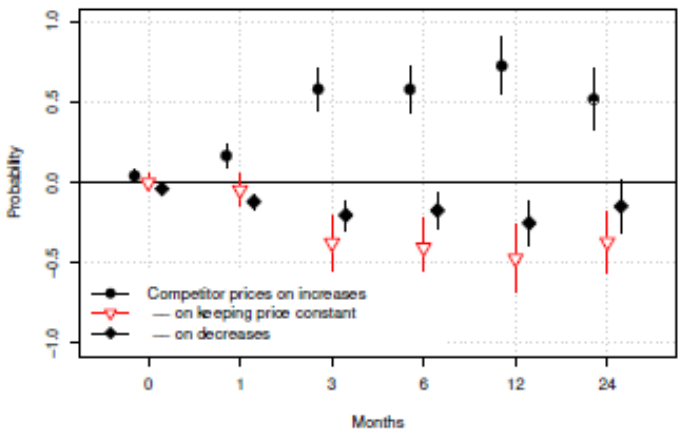
(a) Energy cost shock



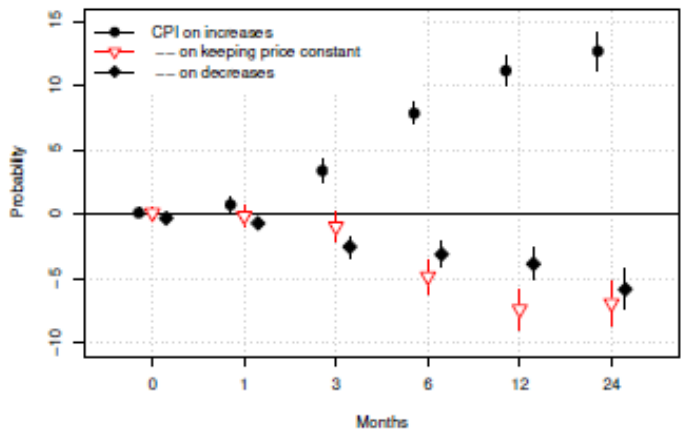
(b) Import cost shock



(c) Competitor prices



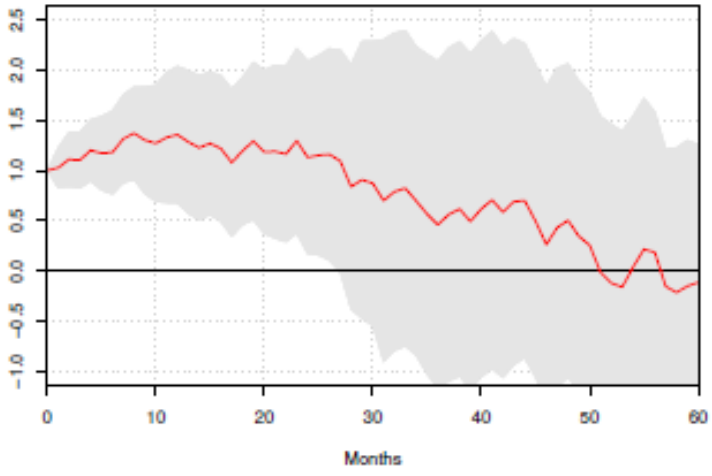
(d) Consumer price index



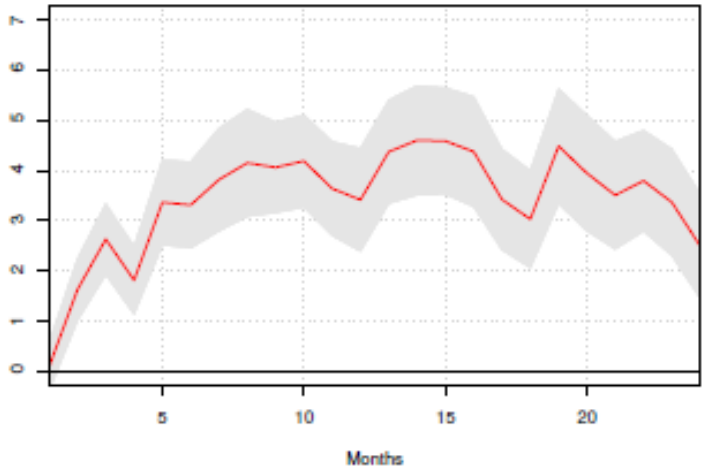
Import and Energy Cost Shocks

- Both shocks persistent at firm-level, but $\phi^{E}_{jt-1+h}\Delta p^{E}_{t+h}$ more pervasive effects than $\phi^{M}_{jt-1+h}\Delta p^{M}_{jt+h}$

(a) Shock



(b) Total variable cost



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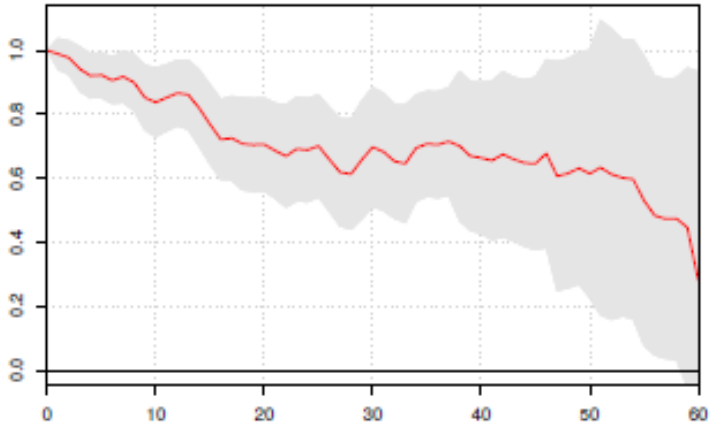

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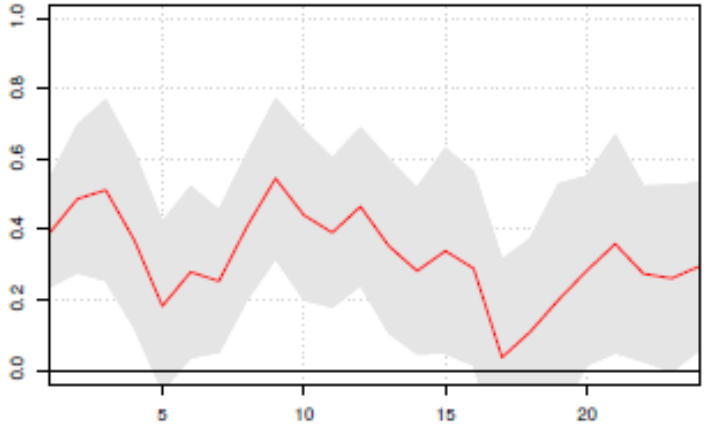
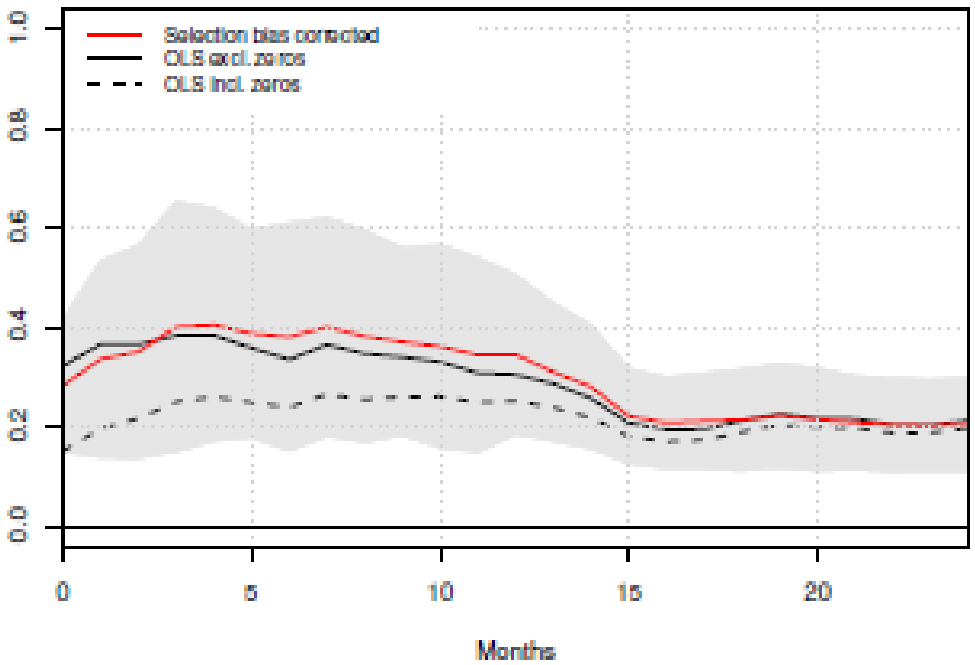


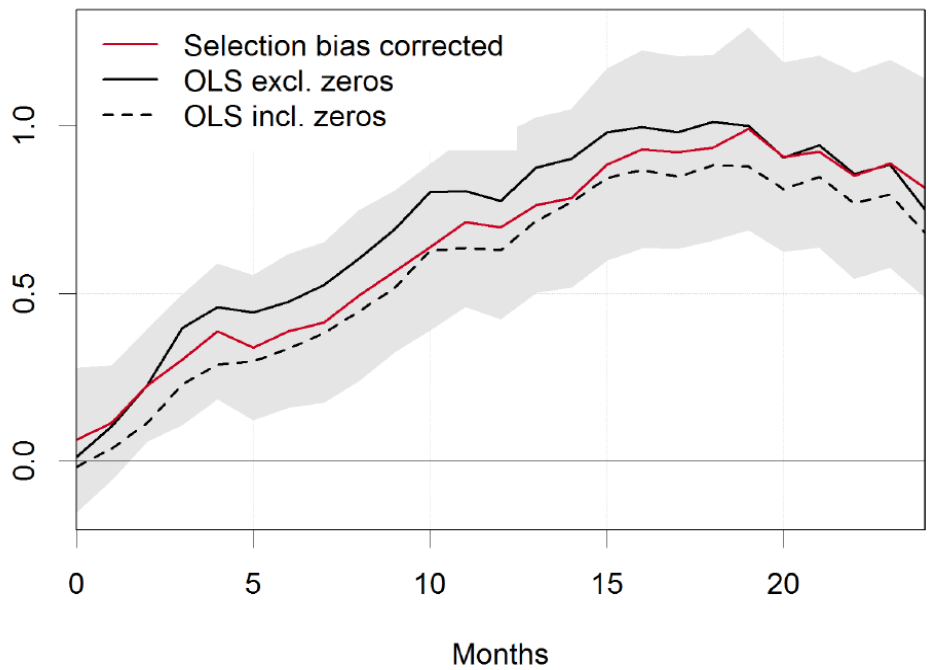
Intensive Margin and Selection (2nd Step)

- Price dynamics in response to 1% cost shocks

Import Shock



Energy Shock



Selection Correction Statistically Significant

- But quantitatively small, robust to using multinomial probit

	ΔP^O	ΔP^M	$\Delta \bar{P}_{-j}$	Selection			N	$R2$
				Decrease	Unchanged	Increase		
k=0	0.0569	0.2826***	0.1740***	−0.1007***	0.0000	0.0738***	54,653	0.431
k=1	0.0671	0.3422***	0.2566***	−0.1060***	−0.0004	0.0983***	76,149	0.436
k=2	0.1457*	0.564***	0.2609***	−0.1054***	0.0001***	0.1191***	93,309	0.458
k=3	0.1837*	0.4077***	0.2796***	−0.1069***	0.0015	0.1328***	103,888	0.466
k=4	0.2953**	0.4084***	0.2596***	−0.1147***	0.0027	0.1384***	113,057	0.475
k=5	0.2550*	0.3890***	0.2464***	−0.1191***	0.0042*	0.1425***	121,267	0.479
k=6	0.3240**	0.3806***	0.2418***	−0.1198***	0.0080**	0.1492***	127,366	0.483
k=9	0.4989***	0.3670***	0.2180***	−0.1387***	0.0159***	0.1465***	141,721	0.489
k=12	0.6216***	0.3444***	0.2255***	−0.1629***	0.0241**	0.1353***	149,625	0.488
k=15	0.8219***	0.2218***	0.2016***	−0.1909***	0.0234*	0.1251***	151,142	0.489
k=18	0.8507***	0.2170***	0.1869***	−0.2089***	0.0220	0.1199***	150,493	0.490
k=21	0.8656***	0.2112***	0.1475***	−0.2247***	0.0274	0.1145***	148,591	0.491
k=24	0.7435***	0.2109***	0.1604**	−0.2505***	0.0293	0.1034***	145,715	0.494

Recall Back-of-the-envelope Decomposition of Margins

- Decompose estimated price adjustment $(\widehat{p}_{t+h} - \widehat{p}_{t-1+h})$ conditional on cost shock for each horizon h:

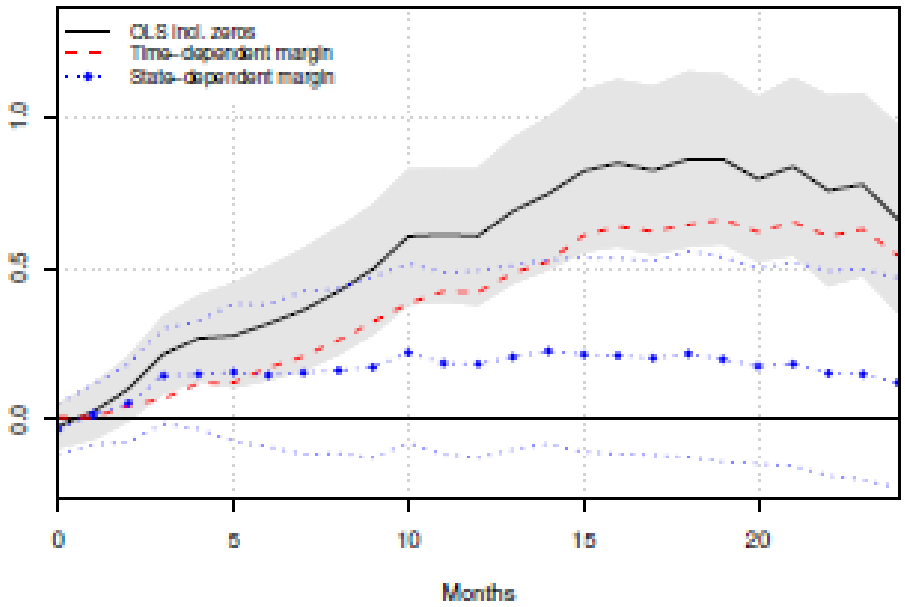
$$\widehat{p}_{t+h} - \widehat{p}_{t-1+h} = \underbrace{\overline{\lambda}_h \left(\widehat{p}^*_{t+h} - \widehat{p}^*_{t-1+h}\right)}_{TD\ MARGIN} + \underbrace{\left[\left(\widehat{p}_{t+h} - \widehat{p}_{t-1+h}\right) - \overline{\lambda}_h \left(\widehat{p}^*_{t+h} - \widehat{p}^*_{t-1+h}\right)\right]}_{SD.\ MARGIN}$$

  where $\widehat{p}_{t+h} - \widehat{p}_{t-1+h} =:$ OLS estimates including zero/non-zero $p_{t+h} - p_{t-1+h}$

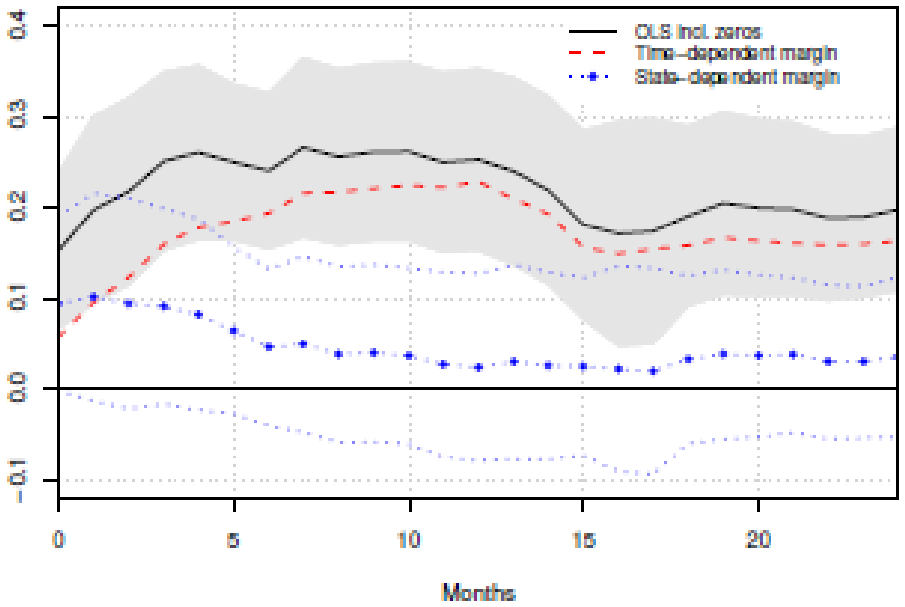
- Recall SD margin includes contributions from both selection and extensive margin

Decomposition: Bulk of Adjustment due to TD Margin

(a) Energy cost shock



(b) Import cost shock



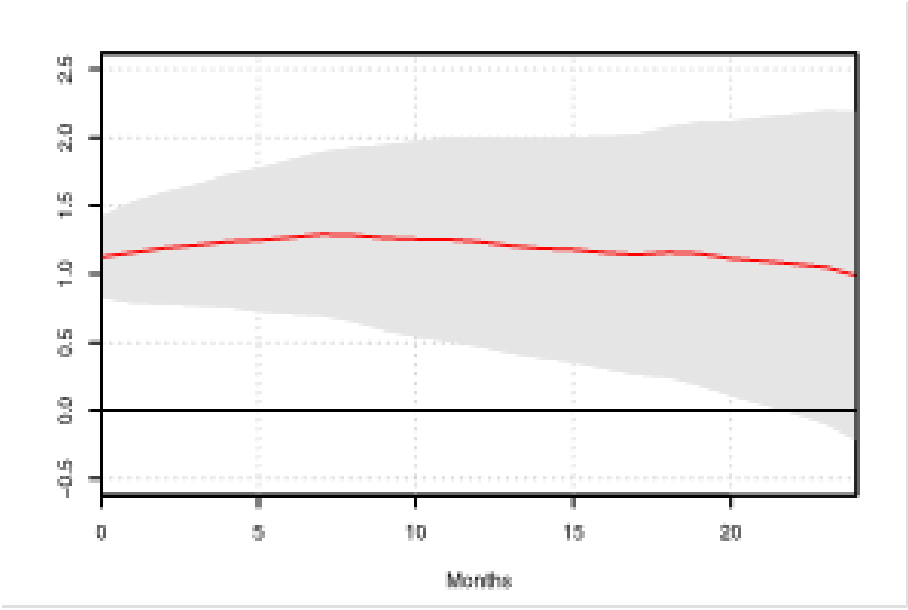
Several Robustness Checks

- Pass-through at firm- instead of product-level (measurement bias)
- Drop exiting products, export prices
- Selection correction with Multinomial Probit (correlated errors in 1st step, no IIA)
- Drop firm-level observable costs
- Sign of shocks

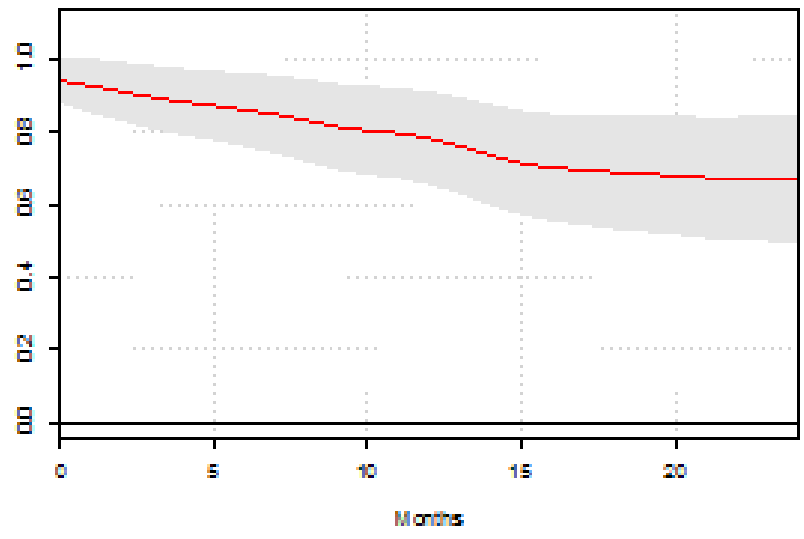
Heterogeneity across Shocks, Sectors, Firms

- Heterogeneous adjustment across two shocks mainly due to response of **reset prices, lower than implied Calvo adjustment:**

Energy Shock



Import Shock



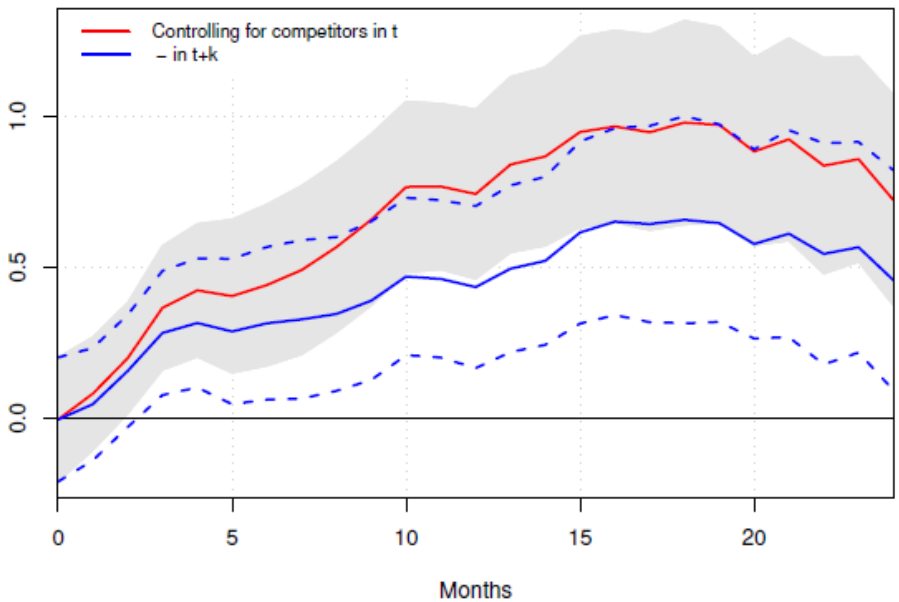
Heterogeneity across Shocks, Sectors, Firms

- Heterogeneous adjustment across two shocks mainly due to response of **reset prices**
- Explore sources of real rigidities:
  - Import shocks largely idiosyncratic, more common component in oil shocks
  - Supply chain/network and "pipeline" effects for oil shocks
  - Larger firms react less to import shock

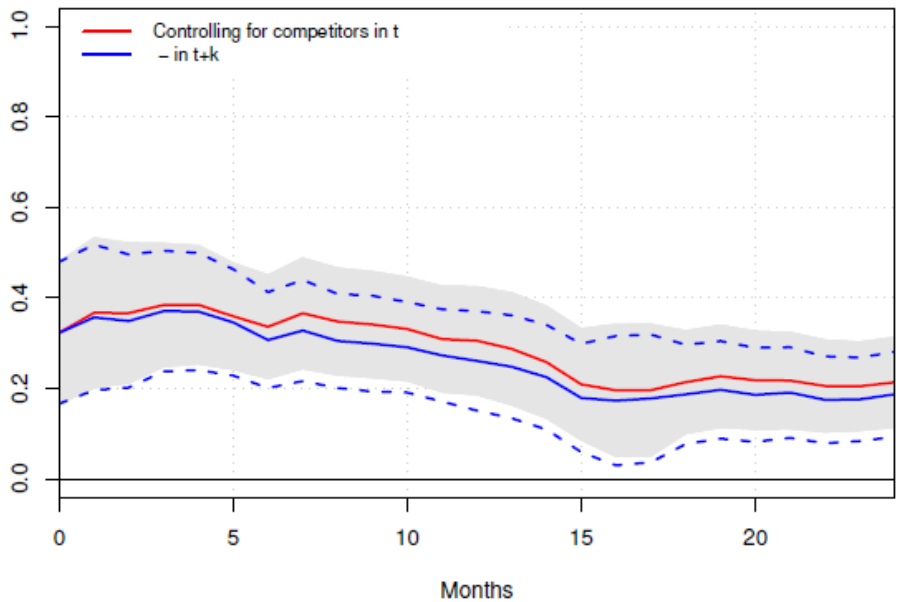
Heterogeneous Shock Adjustment: Controlling for Competitors' Prices in t+h

- Similar results with time fixed effects

(a) Oil price shock

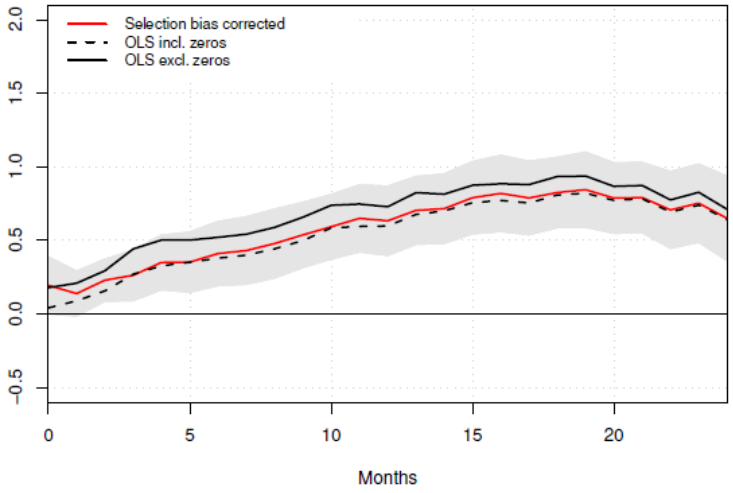


(b) Import cost shock

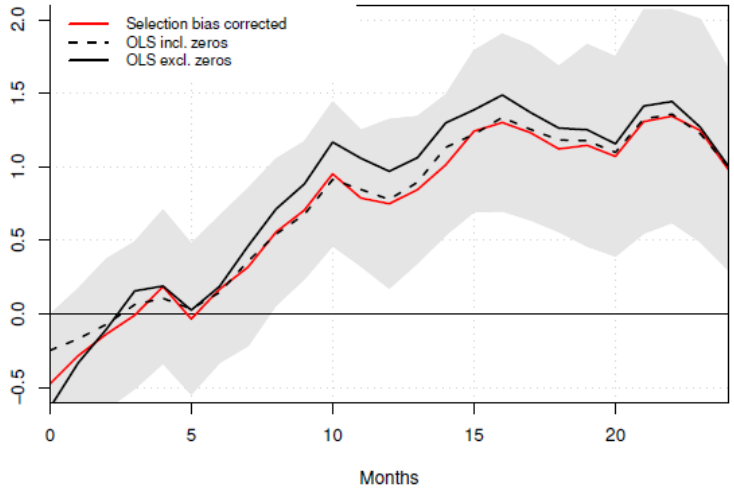


Heterogeneous Adjustment: Pipeline Effects of Oil Shock

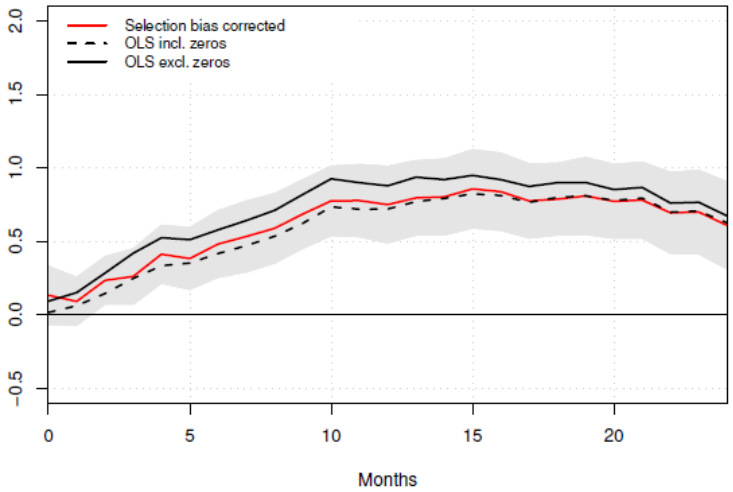
(a) Intermediate goods



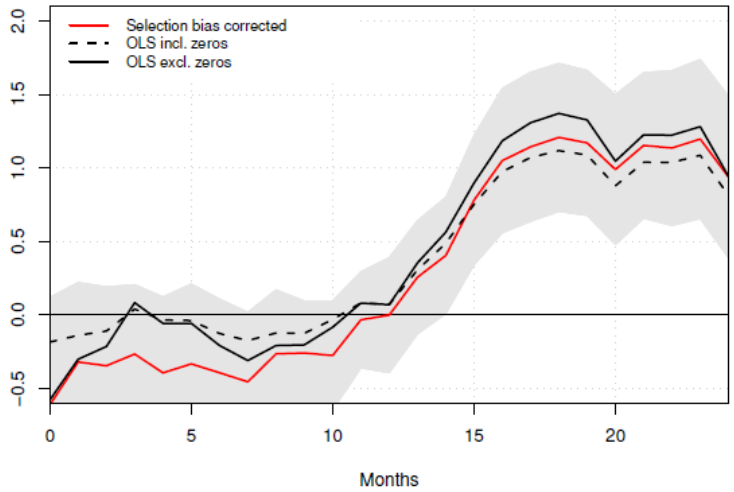
(b) Final goods



(c) High oil exposure

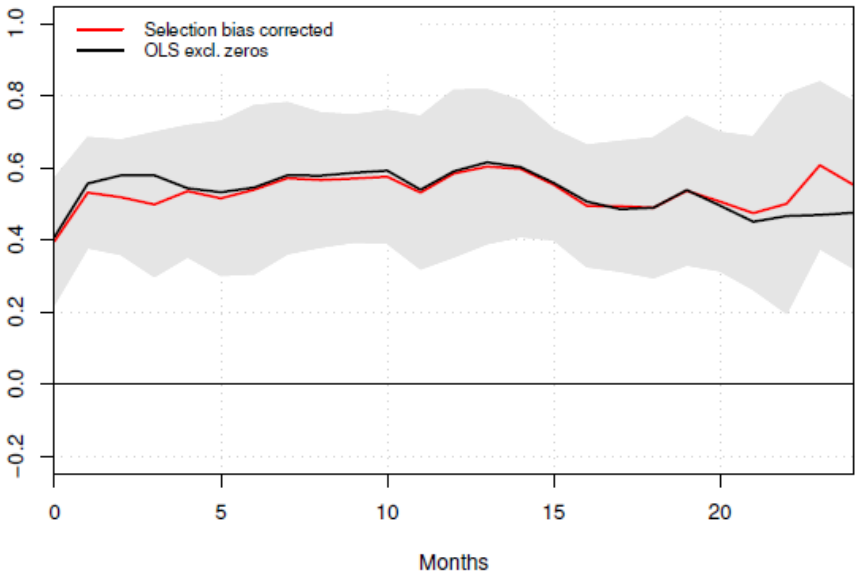


(d) Low oil exposure

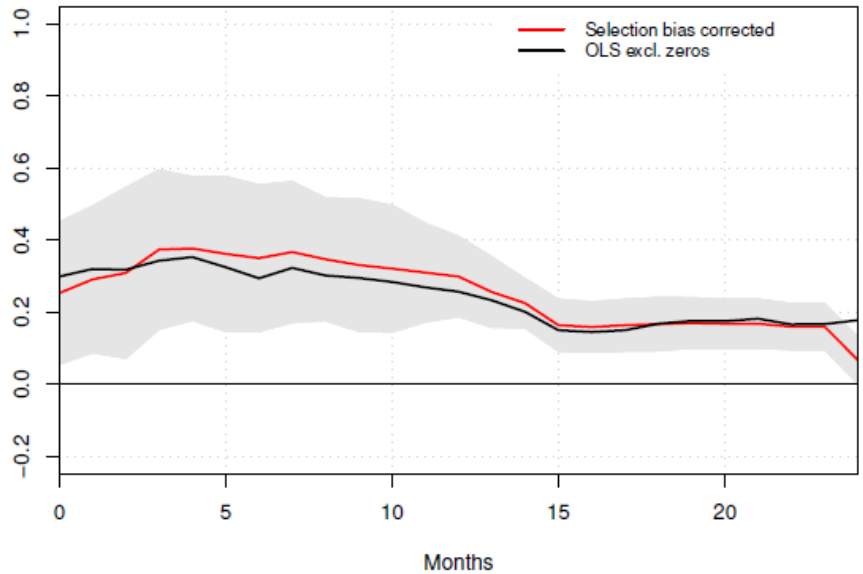


Heterogeneous Adjustment: Larger Firms React less to Import Shock

(a) $<$ 100 employees



(b) $\geq$ 100 employees



Conclusions

Evidence on price adjustment in multiproduct firms in line with (hybrid) SD models with little selection, strong real rigidities

- Synchronization and state-dependence:
  - Price change probability increasing with fraction of other prices changing, the stronger the more products
  - Probability depends on (firm, industry and aggregate) shocks
- Intensive margin and shock, sector and firm heterogeneity
  - Small selection "bias", evidence of real rigidities
  - Gradual adjustment to aggregate energy/oil shocks due to "pipeline", second round effects
  - Adjustment to more idiosyncratic import costs fast but smaller for larger firms
- Future research:
  - Does SD matter for large shocks?
  - How do strategic complementarities interact with nominal rigidities?