

Price Updating with Production Networks

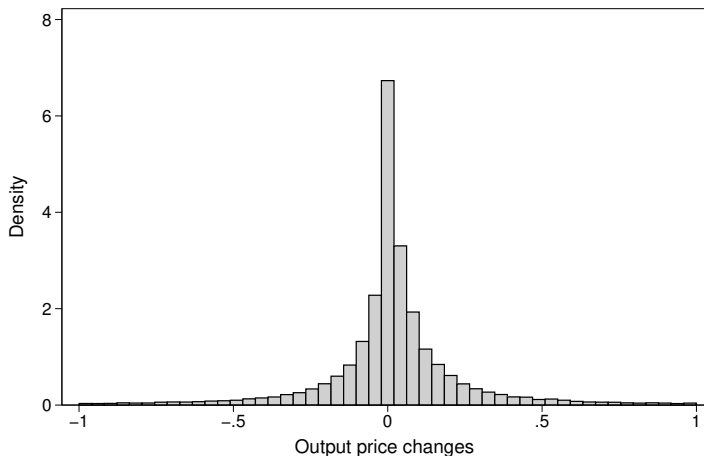
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Year-on-year producer price changes (Belgium, pooled 2002-2014)



- ▶ symmetric
- ▶ large variance: $p_{10}/p_{90}: \pm .20$
- ▶ robust by year, within product, within firm, other datasets (micro PPI, ...)

Why do firms adjust their output prices?

With per-period cost minimization, firm j changes its output price as

$$\underbrace{d \ln p_{jt}}_{\text{price}} = \underbrace{d \ln c_{jt}}_{\text{marginal cost}} + \underbrace{d \ln \mu_{jt}}_{\text{markup}}$$

Canonical models with complete pass-through

- ▶ no/constant markups: $d \ln \mu_{jt} = 0$
- ▶ e.g. perfect competition, monop. comp. with CES preferences (hom/het firms)

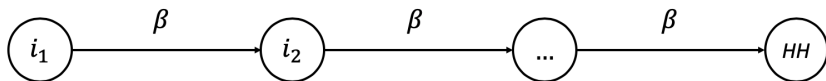
Inconsistent with repeated empirical evidence of incomplete pass-through

- ▶ variable markups: $d \ln \mu_{jt} \neq 0$
- ▶ macro: exchange rate disconnect; imports vs CPI variance
- ▶ micro: sector-specific (partial equilibrium) studies

CPI response depends critically on passthrough rate

Thought experiment: line network with n producers

- ▶ How much of initial shock to i_1 ends up with the final consumer (HH)?



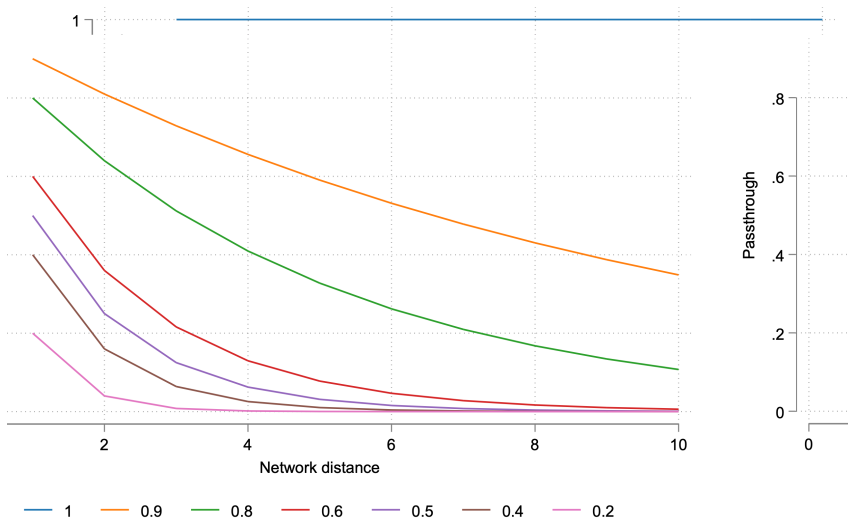
Passthrough models

- ▶ Complete: shock fully borne by HH, even as $n \rightarrow \infty$
- ▶ Incomplete: shock decays at rate β^n , and $\beta^n \rightarrow 0$ as $n \rightarrow \infty$
- ▶ For $n = 4$: $\beta = 1 \Rightarrow \beta^n = 1$ but $\beta = 0.5 \Rightarrow \beta^n = 1/16$

More generally, ultimate CPI response depends on

- ▶ Input-output structure of production network
- ▶ Location of the initial shock (Hulten, 1978; Gabaix, 2011; Acemoglu et al., 2012; Baqaee, 2018; Baqaee and Farhi, 2019a,b; 2020)

CPI response depends critically on passthrough rate



This paper

Questions

- ▶ How do firms change their prices in production networks?
- ▶ What is the impact of firm-level price changes on aggregate prices?

Why is it important?

- ▶ Aggregation: identifying micro origins of aggregate price fluctuations
- ▶ Welfare: reallocation of surplus across producers and consumers

Network propagation literature assumes perfect pass-through

- ▶ All shocks ultimately end up with the final customer and thus CPI

Existing studies mostly rely on partial data and/or structural assumptions

- ▶ Marginal costs have to be estimated or backed out
- ▶ Missing link between imports and final consumption price volatility

What we do

1. Non-parametric framework of price updating

- ▶ Very light assumptions on market structure, technology, demand
- ▶ Assumptions: per-period cost minimization, CRS wrt. variable inputs

2. No need to estimate marginal costs

- ▶ Generally: $d \ln c_{jt} = f(d \ln p_{1jt}, \dots, d \ln p_{Njt}, d \ln z_{jt})$
- ▶ We observe all $d \ln p_{ijt}$ in the data and estimate $d \ln z_{jt}$

3. Estimate elasticities: pass-through, productivity, strategic complementarities

- ▶ Multiple instruments used: TFP shocks of suppliers, import prices, producer prices

4. Propagation and aggregation to CPI

- ▶ Depends on nature of shock, IO structure, pass-through, strategic complementarities

5. Detailed product classification concordance

- ▶ $m : n$ correspondences in production (PC) and trade (CN)
- ▶ No synthetic “family trees”, consistent unit of measurement

Related literature

Theory on variable markups, incomplete pass-through

Atkeson-Burstein (2008), Melitz-Ottaviano (2008), Weyl-Fabinger (2013), Atkin-Donaldson (2015), Edmond et al. (2015), Parenti et al. (2017), Arkolakis-Morlacco (2018), Amiti et al. (2019)

→ **Include production networks**

Empirics on variable markups, incomplete pass-through

Burstein-Gopinath (2014), Goldberg-Verboven (2001), Campa-Goldberg (2006), Nakamura-Zerom (2010), Berman et al. (2012), Goldberg-Hellerstein (2013), Fabra-Reguant (2014), Garetto (2016), De loecker et al. (2016)

→ **GE model with welfare implications (doing)**

Production networks, pricing and propagation

Acemoglu et al. (2012), Baqaee (2018), Baqaee & Farhi (2019a,b; 2020), Baqaee et al. (2022)

→ **Endogenous markups**

Concordance methods

Pierce-Schott (2012a, 2012b), Bernard et al. (2018)

→ **Exact mapping, no synthetic aggregation**

Today

General framework of price updating

Data and identification

Empirical results on price updating

Propagation and aggregation

Next steps

Production

Cost function for producer j at time t

$$\overbrace{y_{jt} c_{jt} ((1 + \tau_{1j}) p_{1t}, \dots, (1 + \tau_{nj}) p_{nt}, z_{jt})}^{\text{constant returns}} + \underbrace{F_{jt}}_{\text{fixed costs}}$$

unit cost

- ▶ τ_{ij} : bilateral wedges (e.g. transport costs)
- ▶ z_{jt} : productivity
- ▶ F_{jt} : fixed costs

Notes

- ▶ Embeds network structure of production: inputs i and outputs j
- ▶ CRS wrt variable inputs. IRS from fixed costs, DRS: add firms that provide factors
- ▶ General technological change (Hicks-neutral in empirics)

Pricing and markups

General pricing equation under static cost minimization

$$\ln p_{jt} = \ln c_{jt} ((1 + \tau_{1j}) p_{1t}, \dots, (1 + \tau_{Nj}) p_{Nt}, z_{jt}) + \ln \mu_{jt} (p_{jt}, \mathcal{P}_{-jt}; \xi_{jt})$$

- ▶ $\mathcal{P}_{-jt}$: price index of j 's environment (e.g. agg P-index, strat. comp.)
- ▶ ξ_{jt} : quantity shifter (e.g. price elasticity of demand)

Notes

- ▶ Profit maximization not necessary (e.g. cost-plus pricing, price capping)
- ▶ Nests no, constant and variable markups
- ▶ $\mathcal{P}_{-jt}$ depends on underlying model of price setting (e.g. oligopoly, monop. competition, or just responding to news)
- ▶ Single-product firms: multi-product firms possible with additional assumptions

Price updating

Totally differentiating the pricing equation

$$\begin{aligned} d \ln p_{jt} = & \underbrace{\sum_{i \in \mathcal{S}_{jt}} \frac{\partial \ln c_{jt}}{\partial \ln p_{it}} d \ln p_{it}}_{\text{total input price shock}} + \underbrace{\frac{\partial \ln c_{jt}}{\partial \ln z_{jt}} d \ln z_{jt}}_{\text{productivity shock}} + \underbrace{\frac{\partial \ln \mu_{jt}}{\partial \ln p_{jt}} d \ln p_{jt}}_{\text{own price markup effect}} \\ & + \underbrace{\frac{\partial \ln \mu_{jt}}{\partial \ln \mathcal{P}_{-jt}} d \ln \mathcal{P}_{-jt}}_{\text{environment price index effect}} + \underbrace{\frac{\partial \ln \mu_{jt}}{\partial \xi_{jt}} d \xi_{jt}}_{\text{shifters}} \end{aligned}$$

where cost elasticity is given by its input share (envelope theorem)

$$\frac{\partial \ln c_{jt}}{\partial \ln p_{it}} = \frac{p_{ijt} x_{ijt}}{\sum_{i \in \mathcal{S}_{jt}} p_{ijt} x_{ijt}} \equiv \omega_{ijt}$$

Towards estimation equation

$$d \ln p_{jt} = \beta_{jt} \underbrace{\sum_{i \in \mathcal{S}_{jt}} \omega_{ijt-1} d \ln p_{it}}_{\text{change in input price index}} + \gamma_{jt} d \ln z_{jt} + \delta_{jt} d \ln \mathcal{P}_{-jt} + \eta_{jt} d \xi_{jt}$$

Coefficients have a structural interpretation as elasticities, consistent with many pricing models

$$\left\{ \begin{array}{l} \beta_{jt} = \frac{1}{1 - \frac{\partial \ln \mu_{jt}}{\partial \ln p_{jt}}} \\ \gamma_{jt} = \frac{1}{1 - \frac{\partial \ln \mu_{jt}}{\partial \ln p_{jt}}} \frac{\partial \ln y_{jt}}{\partial \ln z_{jt}} \\ \delta_{jt} = \frac{1}{1 - \frac{\partial \ln \mu_{jt}}{\partial \ln p_{jt}}} \frac{\partial \ln \mu_{jt}}{\partial \ln \mathcal{P}_{-jt}} \\ \eta_{jt} = \frac{1}{1 - \frac{\partial \ln \mu_{jt}}{\partial \ln p_{jt}}} \frac{\partial \ln \mu_{jt}}{\partial \xi_{jt}} \end{array} \right.$$

Hypothesis: H_0 : constant/no markups ($\beta_{jt} = 1$); H_a : variable markups ($\beta_{jt} \neq 1$)

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Variables

Datasets (2002-2014)

- ▶ Production: firm, product (PC8), year, value, quantity, unit
- ▶ Int'l trade: firm, product (CN8), country, year, value, quantity, unit
- ▶ Domestic production network: seller, buyer, year, value
- ▶ Annual accounts: sales, inputs, employment, NACE codes

Estimate productivity shocks

- ▶ Estimate $TFPq$ (Hicks neutral)

Calculate change in firm's environment prices $\mathcal{P}_{-jt}$

- ▶ Depends on your underlying competition model of choice
- ▶ Sufficient statistic for many oligopolistic models: market shares and competitors' prices (best response functions)

$$d \ln \mathcal{P}_{-jt} = \sum_{l \neq j \in PC8} \lambda_{ljt-1} d \ln p_{lt}$$

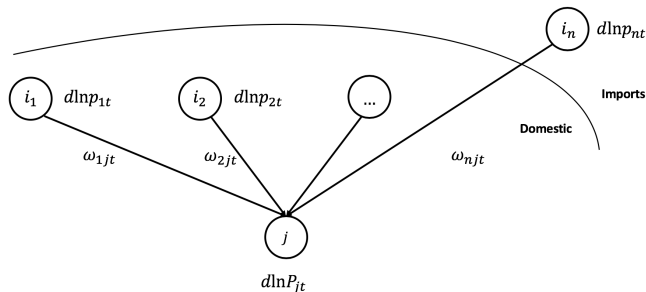
Input and output prices

Change in input price index $d \ln P_{jt} = \sum_{i \in \mathcal{S}_{jt}} \omega_{ijt-1} d \ln p_{it}$

- ▶ We observe all input shares (domestic and imports) $\omega_{ijt} = \frac{p_{ijt} x_{ijt}}{\sum_{i \in \mathcal{S}_{jt}} p_{ijt} x_{ijt}}$
- ▶ $d \ln p_{it}$ from Prodcum (domestic) and Comext (imports)

Change in output price $d \ln p_{jt}$

- ▶ Identify continuing products year-on-year (own concordances)
- ▶ Domestic prices, corrected for re-exports (Prodcum and Comext exports)



Identification

Goal: obtain consistent estimates for parameters $\theta = (\beta, \gamma, \delta)$

$$d \ln p_{jt} = \alpha + \beta d \ln P_{jt} + \gamma d \ln z_{jt} + \delta d \ln \mathcal{P}_{-jt} + \eta d \xi_{st} + \varepsilon_{jt}$$

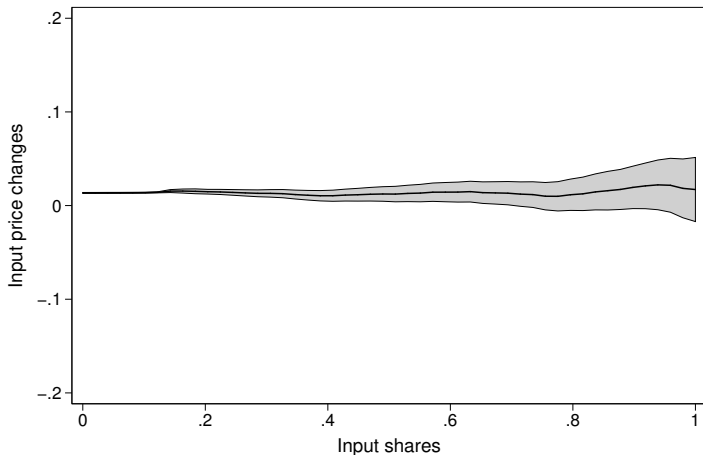
Problem: OLS estimates are biased and inconsistent

- ▶ simultaneity of prices (co-movement, best response)
- ▶ measurement error in regressors (since use unit values)
- ▶ selection bias if $Cov(\omega_{ijt-1}, d \ln p_{it}) \neq 0$ (intensive/extensive margins)

Selection bias: intensive margin

Selection bias if ω_{ijt-1} correlates with $d \ln p_{it}$

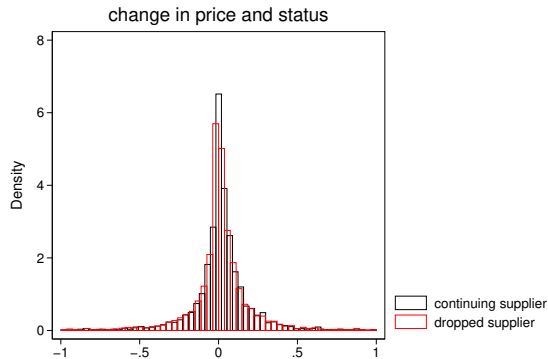
- ▶ E.g. price contracts for important inputs
- ▶ Surprising: we find no correlation!



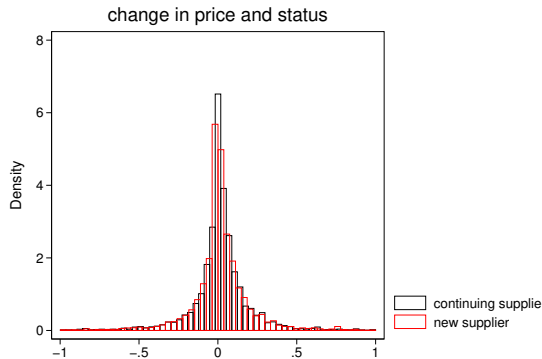
Selection bias: extensive margin

Selection bias if firms add/drop suppliers in response to price shocks

- ▶ 90% of value of input bundle is continuing from any year to the next
- ▶ Firms do not systematically add/drop suppliers in response to shocks
- ▶ Matching on levels (e.g. high productivity or low price) is fine



(a) Continuing vs dropped



(b) Continuing vs added

Simultaneity: Instruments

Instruments for input price index $d \ln P_{jt}$

$$d \ln P_{jt}^{IV} = \sum_{i \in S_j} \omega_{ijt-1} l_{it}$$

where $l_{it} = \left\{ d \ln z_{it}, d \ln \bar{p}_{-it}^{PC8-EU}, d \ln \bar{p}_{-it}^{CN8-EU} \right\}$

Exclusion restriction: $\mathbb{E}(\sum_{i \in S_j} \omega_{ijt-1} l_{it} \varepsilon_{jt}) = 0$, which collapses to $\mathbb{E}(\omega_{ijt-1} \varepsilon_{jt}) = 0, \forall i$, when $i, j \rightarrow \infty$ (GMM).

Instruments for environment price index $d \ln \mathcal{P}_{-jt}$

$$d \ln \mathcal{P}_{-jt}^{IV} = \sum_{l \neq j \in PC4} \lambda_{ljt-1} \left(\sum_{m \neq i \in S_{lt}} \omega_{mlt-1} l_{mt} \right)$$

where $l_{mt} = \left\{ d \ln z_{mt}, d \ln \bar{p}_{mt}^{PC8-EU}, d \ln \bar{p}_{mt}^{CN8-EU} \right\}$ and m are other suppliers to competitor l who are not also supplying j

Exclusion restriction: $\mathbb{E}(\omega_{mlt-1} \varepsilon_{jt}) = 0, \forall m$.

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Price updating

Dep. var.	OLS			IV		
	(i) $d \ln p_{jt}$	(ii) $d \ln p_{jt}$	(iii) $d \ln p_{jt}$	(iv) $d \ln p_{jt}$	(v) $d \ln p_{jt}$	(vi) $d \ln p_{jt}$
$d \ln P_{jt}$	0.260* (0.065)	0.259* (0.065)	0.256* (0.064)	0.521*** (0.063)	0.524*** (0.063)	0.531*** (0.062)
$d \ln Z_{jt}$	-0.106* (0.023)	-0.109** (0.023)	-0.109** (0.023)	-0.107*** (0.005)	-0.110*** (0.005)	-0.109*** (0.005)
$d \ln \mathcal{P}_{-jt}$	0.362** (0.051)	0.347** (0.047)	0.345** (0.046)	0.377*** (0.090)	0.368*** (0.090)	0.403*** (0.098)
FE	year	year + sector	year $\times$ sector	year	year + sector	year $\times$ sector
N	33,787	33,787	33,787	33,718	33,718	33,718
J -test χ^2				3.70	3.21	4.72
[p -value]				[.30]	[.36]	[.19]

Note: Columns (i)-(iii) report OLS estimates, columns (iv)-(vi) reports the second stage of IV estimates employing GMM with 5 instruments. All regressions are pooled over the years 2004-2014. The IV specifications pass all validity tests. Hansen's over-identification J -test statistic cannot reject the null hypothesis that the over-identifying restrictions are valid at the 1% level. Robust standard errors, clustered at the aggregated sector level (5 clusters) in parentheses. Significance: * < 5%, ** < 1%, *** < 0.1%.

Discussion

Results

- ▶ Pass-through is incomplete ($\beta < 1$)
- ▶ Strategic complementarities exist ($\delta > 0$)
- ▶ Generalizes imports/sector studies to full production network

Identification/robustness

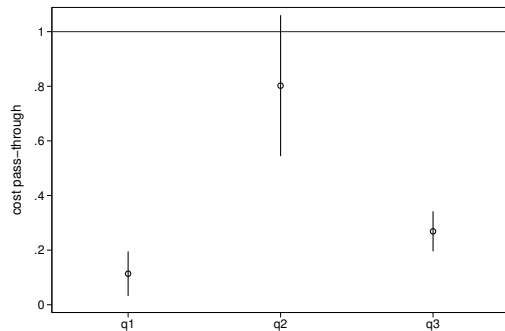
- ▶ IV (GMM) passes all over-identification tests
- ▶ Robust to alternative estimators (LIML, 2SLS)
- ▶ Robust to alternative instruments (Duranton & Turner, 2012)

Heterogeneity: pass-through by sector

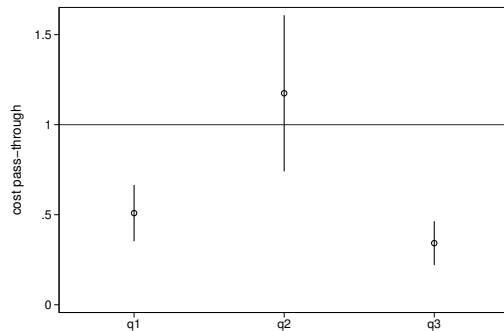
		IV			
NACE Rev.2 sectors		N	β	γ	δ
8-9	Mining and quarrying	398	.933*	-.050	.387
10-12	Food products and beverages	6,023	.340***	-.059***	.512***
13-15	Textiles and apparel	1,363	.229	-.122***	.232**
16	Wood[...]	1,281	.077	-.100***	.192**
17-18	Paper products and media	1,121	.334**	-.119***	.239*
20	Chemicals and chemical products	1,479	.628***	-.061*	.274**
22	Rubber and plastic products	1,159	.344	-.112**	-.067
23	Other non-metallic minerals[...]	2,179	.459**	-.103***	.218
24	Basic metals	468	.486**	-.042	.695***
25	Fabricated metal products[...]	2,841	.391**	-.095***	.374***
26-27	Computer, electronic and[...]	580	.583	-.162***	.035
28-29	Machinery, motor vehicles[...]	254	-1.86	-.058	1.148
31-32	Furniture and other manufacturing	1,342	.541***	-.139***	-.016
33	Repair and installation of machinery/equipment	63	.381	-.007	1.187**

Heterogeneity: idiosyncratic vs common shocks

Setup: Demean input price index by sector-year average, group in terciles (q3: “large cost increase”).



(c) OLS



(d) IV

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Propagation

Pricing equation in reduced form

$$d \ln p_{jt} = \alpha + \beta d \ln P_{jt} + \gamma d \ln z_{jt} + \delta d \ln \mathcal{P}_{-jt} + \eta d \xi_{st} + \varepsilon_{jt}$$

$$d \ln \mathbf{p} = \beta \Omega d \ln \mathbf{p} + \gamma d \ln \mathbf{z} + \delta \Lambda d \ln \mathbf{p} + \eta d \xi$$

$$\iff d \ln \mathbf{p} = \underbrace{[I - \beta \Omega - \delta \Lambda]^{-1}}_{\text{network structure}} \underbrace{(\gamma d \ln \mathbf{z} + \eta d \xi)}_{\text{exogenous shocks}}$$

Intuition

- ▶ Price shocks accumulate through production network Ω
- ▶ Nests other models (e.g. $\beta = 1$ and $\delta = 0$ = no/constant markups)
- ▶ Validity of chosen instruments (see proof appendix)

Any shock has an impact on all moments of $d \ln p_{jt}$

- ▶ Mean and variance: exchange rate disconnect
- ▶ 3rd-4th moments: Symmetric shocks can have asymmetric effects and varying tails

Aggregation

Change in producer price index due to supply shock

$$d \ln \mathbb{P} = \sum_j \nu_j d \ln p_j(\Omega, \beta, \delta, \Lambda; d \ln \mathbf{z}, d\xi)$$

with ν_j some appropriate weight depending on chosen P-index

Provides structural interpretation and micro foundation of PPI

- ▶ Shocks can taper off before reaching final consumers
- ▶ Function of many dimensions of heterogeneity

With incomplete pass-through, aggregation measures fail

- ▶ Solow (1957), Hulten (1978) fail with inefficient economies
- ▶ Baqaee and Farhi (2020) fails with variable markups

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Counterfactuals & applications

Monetary policy

- ▶ Does inflation targeting work as it is intended?
- ▶ Need incomplete adjustment to prices to get real short term effects
- ▶ Mostly model these as nominal rigidities (e.g. Calvo)
- ▶ Alternative explanation: flexible prices with incomplete pass-through

Exchange rate disconnect

- ▶ Macro puzzle: high import price volatility cannot be matched with low consumer price volatility
- ▶ Example introduction: ultimate impact on final prices is $\beta^4 \simeq 0.06$.

Productivity shocks and incomplete pass-through

- ▶ Network shock propagation models mostly assume perfect pass-through
- ▶ With incomplete pass-through, aggregate effects are smaller in terms of consumer surplus
- ▶ Redistribution between producer and consumer surplus

Conclusions

Takeaways

- ▶ Non-parametric model of price updating in production networks
- ▶ Cost pass-through is incomplete
- ▶ Impact on propagation and aggregation
- ▶ Applications in both micro and macro

Next steps

- ▶ Quantitative CPI analysis
- ▶ Welfare and surplus division
- ▶ Counterfactual exercises

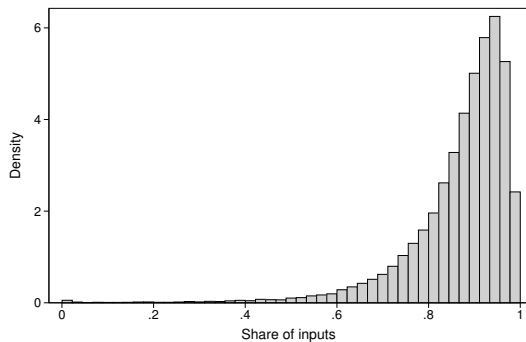
Thank you!

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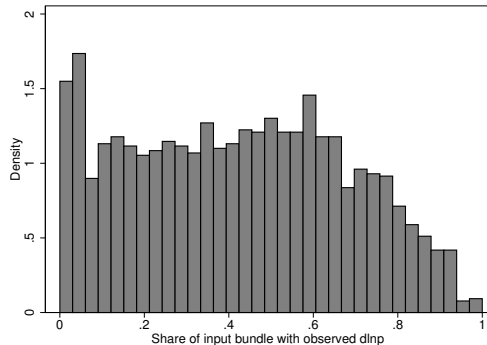
Appendix

Coverage change in input price index

- ▶ Is $\sum_i \omega_{ijt-1} d \ln p_{it}$ a good proxy for $d \ln P_{jt}$?
 - ▶ Continuing inputs from $t - 1$ to t account for 90% of input expenditures on average
 - ▶ Observed share of input bundle with $d \ln p_{it}$ from micro data: 55% on average



(e) Continuing inputs.



(f) $d \ln p_{it}$ from micro data.

Identification (cont'd)

► Estimating equation

$$d \ln p_{jt} = \alpha + \beta d \ln P_{jt} + \gamma d \ln z_{jt} + \delta d \ln \mathcal{P}_{-jt} + \eta d \xi_{st} + \varepsilon_{jt}$$

with $\tilde{\varepsilon} \equiv [I_N - \beta\Omega - \delta\Theta]^{-1}\varepsilon$

► Hence

- $d \ln \mathbf{z}$ and $d\xi$ are exogenous
- valid instruments for $d \ln p_{it}$ and $d \ln p_{lt}$ are exogenous variables of i and l (e.g. their $d \ln z$). (Proof: Bramoulle et al. (2009)).
- Use reduced form for the setup of counterfactuals + IV.

► Notes

- Suff. cond. for invertibility: If $\|\beta + \delta\| < 1$, then $\|\beta\Omega + \delta\Theta\| < 1$ (since $\sum_i \omega_{ij} = 1$ and $\sum_{l \neq j} \theta_{lj} = 1$), and so $[I_N - \beta\Omega - \delta\Theta]$ is non-singular.

Robustness – alternative estimators

- ▶ Underlying assumptions are different. Under constant effects, point estimates should be similar
- ▶ Also test for model mis-specification

Dep. var.	LIML			2SLS		
	(i)	(ii)	(iii)	(iv)	(v)	(vi)
	$d \ln p_{jt}$	$d \ln p_{jt}$	$d \ln p_{jt}$	$d \ln p_{jt}$	$d \ln p_{jt}$	$d \ln p_{jt}$
$d \ln P_{jt}$	0.521*** (0.080)	0.524*** (0.079)	0.531*** (0.077)	0.521*** (0.092)	0.524*** (0.092)	0.531*** (0.062)
$d \ln z_{jt}$	-0.107*** (0.010)	-0.110*** (0.010)	-0.109*** (0.010)	-0.107*** (0.021)	-0.110*** (0.021)	-0.109*** (0.005)
$d \ln \mathcal{P}_{-jt}$	0.373** (0.109)	0.365*** (0.110)	0.401*** (0.117)	0.374*** (0.089)	0.365*** (0.087)	0.402*** (0.098)
FE	year	year + sector	year $\times$ sector	year	year + sector	year $\times$ sector

Robustness – correlated shocks

- Different instruments exploit different sources of variation, hence potential sources of endogeneity are also different (e.g. Duranton and Turner (2012))

	(i)	(ii)	(iii)	(iv)	(v)
Dep. var.	$d \ln p_{jt}$	$d \ln p_{jt}$	$d \ln p_{jt}$	$d \ln p_{jt}$	$d \ln p_{jt}$
$d \ln P_{jt}$	0.357** (0.122)	0.522*** (0.063)	0.408* (0.205)	0.532*** (0.064)	0.529*** (0.064)
$d \ln z_{jt}$	-0.106*** (0.005)	-0.108*** (0.005)	-0.107*** (0.005)	-0.107*** (0.005)	-0.107*** (0.004)
$d \ln \mathcal{P}_{-jt}$	0.778** (0.269)	0.353*** (0.091)	0.452** (0.158)	0.371*** (0.090)	0.362*** (0.091)
$d \ln P_{jt}^{TFP}$	Yes	Yes	Yes	Yes	
$d \ln P_{jt}^{PC}$	Yes	Yes	Yes		Yes
$d \ln P_{jt}^{CN}$	Yes	Yes		Yes	Yes
$d \ln \mathcal{P}_{-jt}^{PC}$	Yes		Yes	Yes	Yes
$d \ln \mathcal{P}_{-jt}^{CN}$		Yes	Yes	Yes	Yes
N	33,718	33,718	33,718	33,718	33,718

First stages

	Year fixed effects		Year + sector fixed effects		Year $\times$ sector fixed effects	
	(i)	(ii)	(iii)	(iv)	(v)	(vi)
Dep. var.	$d \ln P_{jt}$	$d \ln \mathcal{P}_{-jt}$	$d \ln P_{jt}$	$d \ln \mathcal{P}_{-jt}$	$d \ln P_{jt}$	$d \ln \mathcal{P}_{-jt}$
$d \ln z_{jt}$	.010*** (.001)	-.000 (.001)	.010*** (.001)	-.002** (.001)	.009*** (.001)	-.002** (.001)
$d \ln P_{jt}^{TFP}$	-.084*** (.020)	.027** (.008)	-.087*** (.020)	.018* (.008)	-.087*** (.020)	.015 (.008)
$d \ln P_{jt}^{PC}$	.673*** (.068)	.220*** (.058)	.671*** (.068)	.207*** (.058)	.653*** (.068)	.165** (.061)
$d \ln P_{jt}^{CN}$	.831*** (.019)	.179*** (.014)	.832*** (.019)	.181*** (.014)	.824*** (.019)	.159*** (.014)
$d \ln \mathcal{P}_{-jt}^{PC}$	1.123*** (.171)	1.605*** (.144)	1.123*** (.171)	1.513*** (.144)	.762*** (.188)	.727*** (.166)
$d \ln \mathcal{P}_{-jt}^{CN}$	.131***	.798***	.133***	.801***	.121***	.768***

Extension – multi-product firms

► Extension 1 – Model at firm-product level

$$\ln p_{jkt} = \ln c_{jkt} ((1 + \tau_{1j}) p_{1t}, \dots, (1 + \tau_{nj}) p_{nt}, z_{jt}) + \ln \mu_{jkt} (p_{jkt}, \mathcal{P}_{-jkt}; \xi_{jkt})$$

- Additional assumptions
- A1: No physical synergies across products within producers
- A2: Proportionality of inputs to outputs

► Extension 2 – Model at firm level

- Output price index of j

$$d \ln \tilde{P}_{jt} \equiv \sum_k \varphi_{jkt} d \ln p_{jkt}$$

where φ_{jkt} is revenue share of k for j

- A3: Markup shocks are the same across products within firms
- If assumptions do not hold, additional cross-elasticities bias structural estimates of price updating

Extension – multi-product firms (firm-level)

Dep. var.	OLS			IV		
	(i)	(ii)	(iii)	(iv)	(v)	(vi)
	$d \ln \tilde{P}_{jt}$	$d \ln \tilde{P}_{jt}$	$d \ln \tilde{P}_{jt}$	$d \ln \tilde{P}_{jt}$	$d \ln \tilde{P}_{jt}$	$d \ln \tilde{P}_{jt}$
$d \ln P_{jt}$	0.257*	0.256*	0.253*	0.493***	0.496***	0.502***
	(0.063)	(0.063)	(0.062)	(0.059)	(0.059)	(0.059)
$d \ln z_{jt}$	-0.103*	-0.105*	-0.105*	-0.104***	-0.106***	-0.106***
	(0.023)	(0.023)	(0.023)	(0.004)	(0.004)	(0.004)
$d \ln \mathcal{P}_{-jt}$	0.336**	0.321**	0.318**	0.373***	0.363***	0.406***
	(0.049)	(0.046)	(0.047)	(0.085)	(0.086)	(0.093)
FE	year	year + sector	year $\times$ sector	year	year + sector	year $\times$ sector
N	33,787	33,787	33,787	33,718	33,718	33,718
J-test χ^2				3.99	3.67	4.84
[p-value]				[.26]	[.30]	[.18]