# Price Updating in Production Networks

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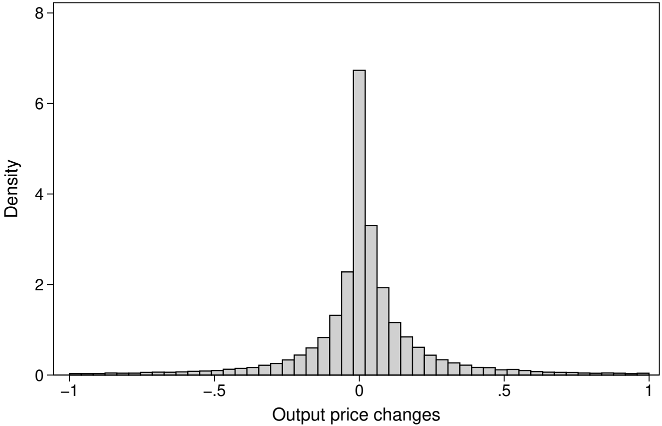
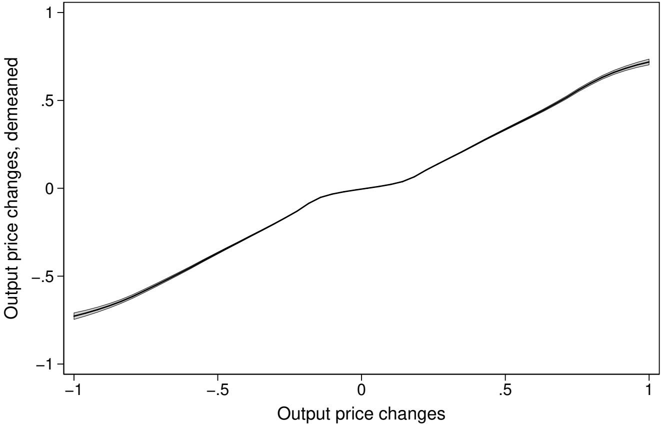
# How do firms change their prices?




- Yearly producer price changes, log differences (Belgium, 2002-2014)
  - Symmetric, centered around zero
  - Highly dispersed (p1/p99: $\pm$ .75)

# How do firms change their prices?




- Co-movement vs idiosyncrasies within 8-digit products
  - Pure co-movement: horizontal line, pure idiosync: 45 degree line
  - Large amounts of within-product heterogeneity

# Motivation

- **Why do firms adjust output prices?**

$$d \ln p = d \ln mc + d \ln \mu$$

If $d \ln \mu = 0$, markups are constant or zero
$\implies$ complete cost pass-through

- **Empirical evidence for incomplete pass-through**
  - Implying markup variability, $d \ln \mu \neq 0$
  - Exchange rate pass-through, sector studies

- **Why is it important?**
  - Micro: efficiency, market power, distribution of welfare effects
  - Macro: inflation forecasting, monetary and exchange rate policy

# This paper

- **Questions**

1. How do firms update prices?
2. How do producer price changes propagate and aggregate?

- **Contributions**

1. Develop general, non-parametric framework of price changes
2. Construct change in firm-level input price index from observables
3. Estimation of cost pass-through in networks
4. Aggregation to inflation with dimensions of micro heterogeneity
5. New procedure to concord product classifications (no family trees)

# Related literature

- **Theory on variable markups, incomplete pass-through**
  Atkeson and Burstein (2008), Melitz and Ottaviano (2008), Weyl and Fabinger (2013), Atkin and Donaldson (2015), Edmond et al. (2015), Amiti et al. (2016), Parenti et al. (2017), Arkolakis and Morlacco (2018)
- **Empirical markups and incomplete pass-through**
  Burstein & Gopinath (2014), Goldberg and Verboven (2001), Campa and Goldberg (2006), Nakamura and Zerom (2010), Berman et al. (2012), Goldberg and Hellerstein (2013), Fabra and Reguant (2014), Garetto (2016), De loecker et al. (2016)
- **Production networks, pricing and propagation**
  Magerman et al. (2016), Grassi (2017), Baqaee (2018), Baqaee & Farhi (2018), Heise (2018), Dhyne, Kikkawa and Magerman (2018)
- **Producers vs consumer price changes**
  Eichenbaum et al. (2011), Alvarez et al. (2016)
- **Concordance methods**
  Pierce and Schott (2012a, 2012b), Bernard et al. (2018)

# Today

General framework of price updating

Data on production networks and prices

Empirical pass-through

Propagation and aggregation

# Pricing and markups

- **General pricing equation under cost minimization**

$$\ln p_{jt} = \ln c_{jt}\left(\left(1+\tau_{1j}\right)p_{1t}, \ldots, \left(1+\tau_{nj}\right)p_{nt}, z_{jt}\right) + \ln \mu_{jt}\left(p_{jt}, \mathcal{P}_{-jt}\right)$$

  - $\tau_{ij}$: bilateral wedge (tariffs, transaction tax, transport costs)
  - $z_{jt}$: efficiency
  - $\mathcal{P}_{-jt}$: price index of $j$'s environment
    (e.g. aggregate, competitors, geography)

- **Notes**
  - Non-parametric cost function, holds for any CRS wrt. variable inputs
  - Profit maximization not required
  - Allow for non-neutral technological change
  - Consistent with no, constant or variable markups
  - $\mathcal{P}_{-jt}$ depends on underlying model of price setting
  - Multi-product firms generalization

# Price updating

- **Total differentiation of pricing equation**

$$d \ln p_{jt} = \underbrace{\sum_{i \in \mathcal{S}_{jt}} \frac{\partial \ln c_{jt}}{\partial \ln p_{it}} d \ln p_{it}}_{\text{total input price shock}} + \underbrace{\frac{\partial \ln c_{jt}}{\partial \ln z_{jt}} d \ln z_{jt}}_{\text{productivity shock}}$$

$$+ \underbrace{\frac{\partial \ln \mu_{jt}}{\partial \ln p_{jt}} d \ln p_{jt}}_{\text{own price markup effect}} + \underbrace{\frac{\partial \ln \mu_{jt}}{\partial \ln \mathcal{P}_{-jt}} d \ln \mathcal{P}_{-jt}}_{\text{environment price index effect}}$$

- where (envelope theorem)

$$\frac{\partial \ln c_{jt}}{\partial \ln p_{it}} = \frac{(1 + \tau_{ij}) p_{it} x_{ijt}}{\sum_{i \in \mathcal{S}_{jt}} (1 + \tau_{ij}) p_{it} x_{ijt}} \equiv \omega_{ijt}$$

# Towards estimation equation

$$d \ln p_{jt} = \beta_{jt} \underbrace{\sum_{i \in \mathcal{S}_{jt}} \omega_{ijt-1} d \ln p_{it}}_{\equiv d \ln P_{jt}} + \gamma_{jt} d \ln z_{jt} + \delta_{jt} d \ln \mathcal{P}_{-jt}$$

where the coefficients have a clear interpretation

$$\begin{cases} \beta_{jt} = \frac{1}{1 - \frac{\partial \ln \mu_{jt}}{\partial \ln p_{jt}}} \\ \gamma_{jt} = -\frac{1}{1 - \frac{\partial \ln \mu_{jt}}{\partial \ln p_{jt}}} \frac{\partial \ln y_{jt}}{\partial \ln z_{jt}} \\ \delta_{jt} = \frac{1}{1 - \frac{\partial \ln \mu_{jt}}{\partial \ln p_{jt}}} \frac{\partial \ln \mu_{jt}}{\partial \ln \mathcal{P}_{-jt}} \end{cases}$$

- If constant/no markup, then $\beta_{jt} = 1$, with variable markups, $\beta_{jt} < 1$

# Identification

- **Estimation equation to obtain parameters $\beta$, $\gamma$ and $\delta$**

$$d \ln p_{jt} = \beta d \ln P_{jt} + \gamma d \ln z_{jt} + \delta d \ln \mathcal{P}_{-jt}$$

- **OLS estimates are biased**
  - $d \ln p_{jt}$ simultaneously determined with $d \ln P_{jt}$ (e.g. common price shocks, cyclicality of network)
  - $d \ln p_{jt}$ simultaneously determined with $d \ln \mathcal{P}_{-jt}$ (e.g. strategic best response)
  - Non-random measurement error from unit values instead of prices

- **IV strategy**
  - 3 instruments, based on import prices and TFP shocks
  - Only affect output prices through input prices and environment prices

# Data construction

- **Datasets (2002-2014)**
  - Prodcom: firm, product (PC8), year, value, quantity, unit
  - Int'l trade: firm, product (CN8), country, year, value, quantity, unit
  - NBB B2B Transactions dataset: seller, buyer, year, value in Belgium

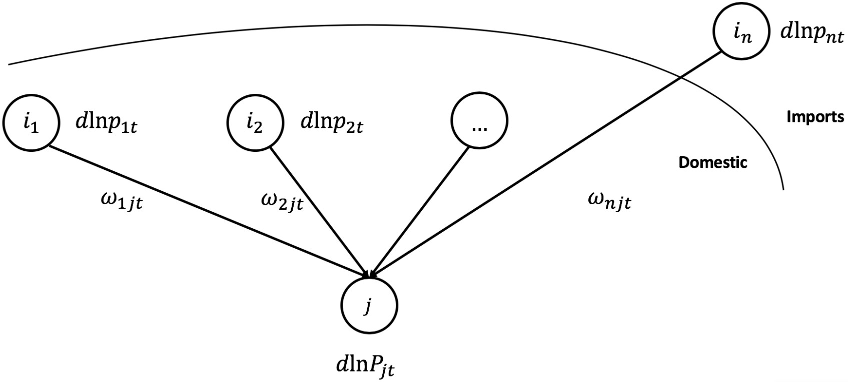
- **Change in domestic output prices** $d \ln p_{jt}$
  - Obtained as change in unit values (Prodcom (NACE B-C) firms)
  - Identify continuing products year-on-year (own concordance method)
  - Corrected for export prices

- **Change in input prices** $d \ln p_{it}$
  - Domestic output price of Prodcom suppliers
  - Imports unit values (continuing importer-product-country obs.)

- **Change in firm's environment prices** $\mathcal{P}_{-jt}$
  - Weighted average of competitor's prices

# Data construction

- **Observe all input shares**
  - Input share $\omega_{ijt} = \frac{m_{ijt}}{\sum_{i \in \mathcal{S}_j} m_{ijt}}$ with $m_{ijt}$ value of shipment $i$ to $j$
  - Correct for capital goods and re-exports



# Cost pass-through

| | OLS | | | IV | | |
|---|---|---|---|---|---|---|
| | (i) | (ii) | (iii) | (iv) | (v) | (vi) |
| Dep. var. | $d \ln p_{jt}$ | $d \ln p_{jt}$ | $d \ln p_{jt}$ | $d \ln p_{jt}$ | $d \ln p_{jt}$ | $d \ln p_{jt}$ |
| $d \ln P_{jt}$ | 0.229*** | 0.199*** | 0.192*** | 0.440*** | 0.388*** | 0.379*** |
| | (0.032) | (0.029) | (0.029) | (0.056) | (0.058) | (0.047) |
| $d \ln z_{jt}$ | -0.091*** | -0.094*** | -0.095*** | -0.089*** | -0.092*** | -0.092*** |
| | (0.008) | (0.008) | (0.008) | (0.008) | (0.008) | (0.008) |
| $d \ln \mathcal{P}_{-jt}$ | 0.334*** | 0.314*** | 0.308*** | 0.277*** | 0.253*** | 0.267*** |
| | (0.029) | (0.029) | (0.028) | (0.039) | (0.041) | (0.033) |
| FE(year) | no | yes | yes | no | yes | yes |
| FE(sector) | no | no | yes | no | no | yes |
| N | 23,590 | 23,590 | 23,590 | 20,722 | 20,722 | 20,722 |

- Pass-through is incomplete
- Both own costs and other prices matter
- Overwhelming majority of pass-through remains after demeaning

# Propagation

- **Price updating in production networks**

$$d \ln \mathbf{p} = [I - \beta\Omega - \delta\Theta]^{-1} \, d\mathbf{M}$$

  where

  - $\beta$ is the $N \times N$ diagonal matrix of pass-through rates
  - $\Omega$ is the $N \times N$ matrix of cost-based expenditure weights
  - $\delta$ is the $N \times N$ diagonal matrix of reaction to other prices
  - $\Theta$ is the $N \times N$ matrix of weights for the environment's price index
  - $d\mathbf{M} \equiv \lambda d \ln \mathbf{M}$ is the $N \times 1$ vector of exogenous shocks $d \ln \mathbf{M}$ with weights $\lambda$

- **Intuition**
  - Exogenous shocks propagate through production network $\Omega$
  - Account for incomplete pass-through $\beta$ and environment's prices $\delta\Theta$
  - Weights $\lambda$ depend on type of shock (e.g. import prices, TFP)

# Aggregation

- **Change in producer price index due to shock**

$$d \ln \mathbb{P} = \sum_j \nu_j d \ln p_j(\beta, \Omega, \delta, \Theta, d\mathbf{M})$$

- **Ultimately a function of**
  - Network structure of production at the firm level (heterogeneity)
  - Incomplete pass-through of cost shocks through production network
  - Responses to environment's prices
  - Nature of shock

- **With incomplete pass-through, typical aggregation measures fail**
  - Heterogeneity along several dimensions matter
  - Cannot match import price shocks to inflation directly
  - Example: 10% shock on import price, $\beta = 0.44$, line economy with 4 firms, passthrough at final stage is $0.44^4 = .04$. So 10% import shock ends up changing the last producer's price with only 0.4%

# Conclusions

- **Takeaways**
  - General, non-parametric model of price updating in production networks
  - Cost pass-through is incomplete
  - Implications for change in aggregate price index
- **From there**
  - GE counterfactuals (imports, TFP)
  - Heterogeneity in pass-through rates

# Robustness – weighted regressions

| | WLS | | | IV (weighted) | | |
|---|---|---|---|---|---|---|
| | (i) | (ii) | (iii) | (iv) | (v) | (vi) |
| Dep. var. | $d \ln p_{jkt}$ | $d \ln p_{jkt}$ | $d \ln p_{jkt}$ | $d \ln p_{jkt}$ | $d \ln p_{jkt}$ | $d \ln p_{jkt}$ |
| $d \ln P_{jkt}$ | 0.312*** | 0.280*** | 0.259*** | 0.529*** | 0.499*** | 0.462*** |
| | (0.070) | (0.067) | (0.065) | (0.093) | (0.083) | (0.105) |
| $d \ln z_{jkt}$ | -0.049* | -0.051* | -0.049* | -0.070*** | -0.072*** | -0.064* |
| | (0.023) | (0.021) | (0.021) | (0.018) | (0.018) | (0.025) |
| $d \ln \mathcal{P}_{-jkt}$ | 0.407*** | 0.386*** | 0.418*** | 0.405*** | 0.402*** | 0.418*** |
| | (0.057) | (0.056) | (0.052) | (0.097) | (0.097) | (0.061) |
| FE(year) | no | yes | yes | no | yes | yes |
| FE(sector) | no | no | yes | no | no | yes |
| N | 23,590 | 23,590 | 23,590 | 20,722 | 20,722 | 20,722 |

*Note:* Columns (i)-(iii) report WLS estimates, columns (iv)-(vi) reports the second stage of weighted IV estimates employing GMM. All regressions are pooled over the years 2004-2014. Robust standard errors between brackets, all clustered at the 4-digit sector level. Significance: * $<$ 5%, ** $<$ 1%, *** $<$0.1%.

- Higher pass-through rates for larger firms

# Robustness – pass-through by sector

| | OLS | | | | IV | | | |
|---|---|---|---|---|---|---|---|---|
| NACE Rev.2 sectors | N | $\beta$ | $\gamma$ | $\delta$ | N | $\beta$ | $\gamma$ | $\delta$ |
| 8-9 – Mining and quarrying | 435 | .363 | -.75* | .001 | 398 | .933* | -.050 | .387 |
| | | (.269) | (.033) | (.100) | | (.367) | (.038) | (.242) |
| 10-12 – Manufacture of food products and beverages | 6242 | .360*** | -.055*** | .362*** | 6,023 | .340*** | -.059*** | .512*** |
| | | (.072) | (.012) | (.095) | | (.080) | (.012) | (.054) |
| 13-15 – Manufacture of textiles and apparel | 1,184 | .306*** | -.114** | .219*** | 1,363 | .229 | -.122*** | .232** |
| | | (.081) | (.035) | (.057) | | (.162) | (.028) | (.080) |
| 16 – Manufacture of wood[...] | 1,294 | .031 | -.107*** | .347*** | 1,281 | .077 | -.100*** | .192** |
| | | (.022) | (.029) | (.071) | | (.146) | (.024) | (.059) |
| 17-18 – Manufacture of paper products and media | 1,238 | .047 | -.141*** | .567** | 1,121 | .334** | -.119*** | .239* |
| | | (.074) | (.018) | (.090) | | (.134) | (.027) | (.119) |
| 20 – Manufacture of chemicals and chemical products | 1,630 | .336** | -.050* | .310*** | 1,479 | .628*** | -.061* | .274** |
| | | (.116) | (.023) | (.067) | | (.173) | (.026) | (.097) |
| 22 – Manufacture of rubber and plastic products | 1,240 | .177*** | -.105*** | .251 | 1,159 | .344 | -.112** | -.067 |
| | | (.034) | (.015) | (.162) | | (.197) | (.034) | (.139) |
| 23 – Manufacture of other non-metallic mineral[...] | 2,300 | .06 | -.108*** | .373*** | 2,179 | .459** | -.103*** | .218 |
| | | (.058) | (.017) | (.055) | | (.147) | (.021) | (.237) |
| 24 – Manufacture of basic metals | 685 | .579*** | -.034 | .424*** | 468 | .486** | -.042 | .695*** |
| | | (.123) | (.028) | (.057) | | (.185) | (.037) | (.178) |
| 25 – Manufacture of fabricated metal products[...] | 3,574 | .215* | -.096*** | .376*** | 2,841 | .391** | -.095*** | .374*** |
| | | (.088) | (.021) | (.061) | | (.142) | (.017) | (.093) |
| 26-27 – Manufacture of computer, electronic and[...] | 798 | .108 | -.176 | .284** | 580 | .583 | -.162*** | .035 |
| | | (.119) | (.041) | (.101) | | (.294) | (.041) | (.167) |
| 28-29 – Manufacture of machinery, motor vehicles[...] | 818 | -.002 | -.073 | .302** | 254 | -1.86 | -.058 | 1.148 |
| | | (.111) | (.040) | (.082) | | (3.112) | (.068) | (1.300) |
| 31-32 – Manufacture of furniture and other manufacturing | 1,489 | .182*** | -.122*** | .251*** | 1,342 | .541*** | -.139*** | -.016 |
| | | (.046) | (.027) | (.061) | | (.160) | (.020) | (.199) |
| 33 – Repair and installation of machinery and equipment | 131 | -.705 | -.086 | .305*** | 63 | .381 | -.007 | 1.187** |
| | | (.155) | (.095) | (.059) | | (1.082) | (.117) | (.435) |

# Extension – multi-product firms

- **Extension 1 – Model at firm-product level**

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

- 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 $\varphi_{jkt}$ is revenue share of $k$ for $j$
  - A3: Markup shocks are the same across products within firms

# Results – multi-product firms (firm-level)

| | OLS | | | IV | | |
|---|---|---|---|---|---|---|
| | (i) | (ii) | (iii) | (iv) | (v) | (vi) |
| Dep. var. | $d \ln \tilde{P}_{jt}$ | $d \ln \tilde{P}_{jt}$ | $d \ln \tilde{P}_{jt}$ | $d \ln \tilde{P}_{jt}$ | $d \ln \tilde{P}_{jt}$ | $d \ln \tilde{P}_{jt}$ |
| $d \ln P_{jkt}$ | 0.236*** | 0.202*** | 0.197*** | 0.436*** | 0.374*** | 0.368*** |
| | (0.032) | (0.030) | (0.029) | (0.055) | (0.056) | (.045) |
| $d \ln z_{jt}$ | -0.087*** | -0.090*** | -0.092*** | -0.086*** | -0.089*** | -0.088*** |
| | (0.008) | (0.008) | (0.008) | (0.008) | (0.008) | (0.007) |
| $d \ln \mathcal{P}_{-jkt}$ | 0.295*** | 0.272*** | 0.267*** | 0.260*** | 0.234*** | 0.250*** |
| | (0.026) | (0.026) | (0.025) | (0.040) | (0.040) | (0.030) |
| FE(year) | no | yes | yes | no | yes | yes |
| FE(sector) | no | no | yes | no | no | yes |
| N | 23,733 | 23,733 | 23,733 | 20,844 | 20,844 | 20,844 |

*Note:* Columns (i)-(iii) report OLS estimates, columns (iv)-(vi) reports the second stage of IV estimates employing GMM. All regressions are pooled over the years 2003-2014. Robust standard errors between brackets, all clustered at the 4-digit sector level. Significance: * $<$ 5%, ** $<$ 1%, *** $<$0.1%.