Semi-Parametric Bounds for Weighted Harmonic Means of Price-Cost Markups

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Overview (1)

- Harmonic mean of price-cost markups (μ_{it}) in a sample of N firms in year t

$$\overline{\mu}_t^H = \left(\frac{1}{N} \sum_i \left(\frac{1}{\mu_{it}} \right) \right)^{-1}$$

- Weighted harmonic mean (for $\sum_i w_{it} = 1$)

$$\overline{\mu}_t^{WH} = \left(\sum_i w_{it} \left(\frac{1}{\mu_{it}} \right) \right)^{-1}$$

- Recent papers propose the sales-weighted harmonic mean of price-cost markups as an appropriate measure of aggregate market power
  - Yeh et al. (AER, 2022), Edmond et al. (JPE, 2023)

- We develop semi-parametric bounds for weighted harmonic means of price-cost markups

Overview (2)

- The key assumptions required for our semi-parametric bounds are:
  - profit-maximising firms
  - competitive input markets
  - constant returns to scale (CRS) production technologies

- With competitive input markets and profit-maximising firms:

$$\text{revenue returns to scale} = \frac{\text{output returns to scale}}{\text{markup}}$$

- With CRS production technologies, the returns to scale (RTS) in the firm's revenue production function is then the reciprocal of the price-cost markup

- Under these assumptions, bounds for weighted harmonic means of price-cost markups can be calculated, using data on revenue shares only
  - expenditure on inputs as a share of sales revenue
  - available for most inputs (except capital) in company accounts

Overview (3)

- For profit-maximising firms, we develop fully non-parametric bounds for weighted arithmetic means of revenue elasticities
  - for flexible inputs (chosen after seeing current period productivity & demand)
  - and for predetermined/quasi-fixed inputs (chosen before seeing current period productivity & demand)
  - allowing observed sales revenue to differ from the value of production in the same period (changes in inventories)
- Summed over all inputs, these give non-parametric bounds for weighted arithmetic means of the returns to scale in firms' revenue production functions
- With competitive input markets and CRS technologies, the reciprocals of those bounds for weighted arithmetic means of revenue RTS then provide bounds for weighted harmonic means of price-cost markups

Overview (4)

- Why consider bounds for average revenue elasticities?
- With (unobserved) dispersion across firms in price-cost markups, the slope parameters of revenue production functions are heterogeneous
- Implying that the moment conditions exploited by standard econometric approaches are invalid
- Our results suggest that standard econometric estimates of revenue production functions may be materially biased

Overview (5)

- We apply our approach to Compustat data for publicly traded North American firms, similar to that used by De Loecker, Eeckhout and Unger (QJE, 2020)
- We also combine their estimated output elasticities for the Cost of Goods Sold (COGS) with revenue shares to reproduce their estimates of price-cost markups, and construct both weighted harmonic means and weighted arithmetic means of those estimates
- Our main results use sales weights, but similar findings using total costs or COGS weights

Key takeaways

- Our bounds suggest that the weighted harmonic mean of price-cost markups for publicly traded North American firms evolved from an interval between 1.01-1.07 in the early 1980s to an interval between 1.04-1.20 in 2016
- These findings are consistent with:
  - a modest rise in aggregate market power
  - a considerable increase in the cross-section dispersion of price-cost markups
- The weighted arithmetic mean of estimated markups emphasised in DLEU (2020, Figure 1) is much higher, and increased more dramatically over this period
  - increasing from around 1.2 in the early 1980s to around 1.6 in 2016
- These differences reflect:
  - arithmetic mean $>$ harmonic mean with markup dispersion
  - omission of inputs labelled Selling, General, and Administrative expenses (SGA) in company accounts from the main specification of the production function used in DLEU

Revenue Elasticities

- Profit-maximising firms, competitive input markets
- For any input X, any production function, any demand schedule, and any market structure

$$\underbrace{\gamma_{Xit}}_{\text{rev. elas.}} = \frac{\overbrace{\beta_{Xit}}^{\text{output elas.}}}{\underbrace{\mu_{it}}_{\text{markup}}}$$

- Well known for Cobb-Douglas production function, CES demand, and monopolistic competition (Klette and Griliches, JAE, 1996)
- Revenue and output elasticities coincide for price-taking firms ($\mu_{it} = 1$)
- Otherwise revenue elasticity is lower ($\mu_{it} > 1$)
  - downward-sloping demand schedules

Revenue Returns to Scale and Markups

- Summing over all inputs

$$\underbrace{\nu_{it}^{REV}}_{\text{revenue RTS}} = \sum_X \gamma_{Xit} = \frac{\sum_X \beta_{Xit}}{\mu_{it}} = \frac{\overbrace{\nu_{it}}^{\text{output RTS}}}{\mu_{it}}$$

- Assuming CRS production functions ($\nu_{it} = 1$)

$$\nu_{it}^{REV} = \frac{1}{\mu_{it}}$$

- Bounds for arithmetic means of revenue RTS in a sample of firms then imply bounds for harmonic means of price-cost markups
- Implementation requires bounds for arithmetic means of revenue elasticities for each of the inputs

Flexible Inputs (1)

- FOC for profit-maximisation implies

$$\underbrace{\gamma_{X it}}_{\text{rev. elas.}} = \frac{X_{it}}{R_{it}^{*}}$$

  - X_{it} = expenditure on input X
  - $R_{it}^{*} = P_{it} \times Q_{it}$ = value of production

- Sales revenue (R_{it}) may differ from the value of production due to changes in inventories

- Multiplicative measurement error

$$\ln R_{it} = \ln R_{it}^{*} + m_{it} \quad \text{with} \quad E(m_{it}) = 0$$

  - common assumption in the literature on production function estimation

Flexible Inputs (2)

- Combining FOC and measurement assumption, for large N we have

$$\frac{1}{N}\sum_i \gamma_{Xit} \leq \frac{1}{N}\sum_i \left(\frac{X_{it}}{R_{it}}\right)$$

- Upper bound: arithmetic mean of observed revenue shares
  - equality if no measurement error
- And

$$\frac{1}{N}\sum_i \gamma_{Xit} \geq \exp\left[\frac{1}{N}\sum_i \ln\left(\frac{X_{it}}{R_{it}}\right)\right]$$

- Lower bound: geometric mean of observed revenue shares
  - equality if common revenue elasticity
- Corresponding results for weighted means

Predetermined Inputs (1)

- Capital is commonly treated as a predetermined/quasi-fixed/dynamic input in the literature on production function estimation
  - the level of capital is assumed to be chosen before the firm observes its productivity and demand for the current period
  - the control function estimator used by DLEU requires this timing assumption
- FOC for profit-maximisation then implies

$$X_{it} = E_{t-1}(\gamma_{Xit} R^*_{it})$$

- Combining this FOC with the same measurement assumption, and the weak rational expectations assumption
  - forecast errors uncorrelated with information on which the forecasts are conditioned

Predetermined Inputs (2)

- For large N we then have

$$\frac{1}{N}\sum_i \gamma_{X_{it}} \leq \frac{1}{N}\sum_i \left(\frac{X_{it}}{R_{it}}\right)$$

- Upper bound: arithmetic mean of observed revenue shares
- And

$$\frac{1}{N}\sum_i \gamma_{X_{it}} \geq \left[\frac{1}{N}\sum_i \left(\frac{R_{it}}{X_{it}}\right)\right]^{-1}$$

- Lower bound: harmonic mean of observed revenue shares
- Corresponding results for weighted means

Revenue Returns to Scale

- The revenue returns to scale is the sum of the revenue elasticities

$$\nu_{it}^{REV} = \sum_{X} \gamma_{Xit}$$

- Upper bound for arithmetic means of revenue RTS: sum of the corresponding upper bounds for each of the inputs
- Lower bound for arithmetic means of revenue RTS: sum of the corresponding lower bounds for each of the inputs

Price-Cost Markups

- Assuming profit-maximising firms, competitive input markets, CRS production technologies

$$\nu_{it}^{REV} = \frac{1}{\mu_{it}}$$

- Upper bound for harmonic means of price-cost markups: reciprocal of lower bound for corresponding arithmetic means of revenue RTS

- Lower bound for harmonic means of price-cost markups: reciprocal of upper bound for corresponding arithmetic means of revenue RTS

- These semi-parametric bounds allow for any form of:
  - CRS production functions
  - admissable demand schedules
  - unobserved heterogeneity in price-cost markups

Application (1)

- We apply this approach to Compustat company accounts data for publicly traded North American firms, 1955-2022
  - similar to that used by DLEU (2020)
- We obtain annual bounds for weighted average values of quantities of interest within each NAICS 2-digit sector
  - weighted averages are less influenced by extreme values of revenue shares, observed in the data for smaller firms
- We combine these sector-specific bounds to obtain bounds for overall weighted average values of quantities of interest
- Principle: if we know that $\mu_A \leq \mu_A^U$ and $\mu_B \leq \mu_B^U$, we know that the average $\overline{\mu} = (\mu_A + \mu_B)/2 \leq (\mu_A^U + \mu_B^U)/2 = \overline{\mu}^U$
  - extends to any weighted average and > 2 sectors

Application (2)

- We have also obtained annual bounds for overall weighted average values of quantities of interest directly
  - pooling the data for all sectors
- These alternative bounds contain our preferred interval estimates, but imply wider intervals (less sharp bounds)
  - less dispersion of underlying revenue shares within sectors than overall

Data Sources

- Compustat: panel of company accounts for all North American publicly traded companies from 1955 to 2022
  - Sales
  - Cost of Goods Sold (COGS): costs directly attributable to production of specific goods and services (most labour, materials, energy)
  - Selling, General, and Administrative expenses (SGA): costs not directly attributable to production of specific goods and services (logistics, marketing, most R&D, directors remuneration, bonuses)
  - Property, Plant, and Equipment (PPE): tangible fixed capital; we use gross PPE, following DLEU
- Additional data for the construction of the user cost of capital
  - interest rates, actual and expected inflation rates, all from FRED
  - company-year specific CAPM betas, from WRDS beta suite
- We treat SGA as an input
  - larger firms spend more on SGA, just as they do on COGS
  - highly significant explanatory variable in revenue production function specifications

The User Cost of Capital

- We impute capital costs as $\rho_{it} \times PPE_{it}$ and consider two alternative measures of the user cost of capital
- An *ex post* measure, as in DLEU, common across firms in the same year

$$\rho_t^{DLEU} = i_t^{FED} - \pi_t + 0.12$$

  where i_t^{FED} is the average annual FED effective funds rate, π_t is the average annual inflation rate, and 0.12 jointly accounts for the risk premium and depreciation

- A firm-specific *ex ante* measure, using a CAPM risk premium and an expected inflation rate

$$\rho_{it}^{E} = i_t^{10Y} - \pi_t^{E} + 0.07 \cdot \beta_{it} + 0.05$$

  where i_t^{10Y} and π_t^E are the average annual yield on 10 year Treasuries and the 10 years-ahead expected inflation rate, both in December of year $t-1$, 0.07 is the equity premium, β_{it} is the company's stock beta, and 0.05 is depreciation

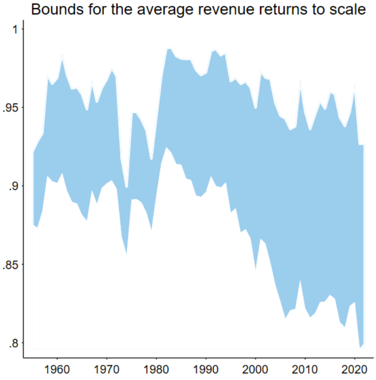
- For observations missing β_{it}, we impute it using the average beta among observations belonging to the same year, sector, sales and age deciles
- ρ_{it}^E is our preferred measure; all results are robust to using the DLEU measure

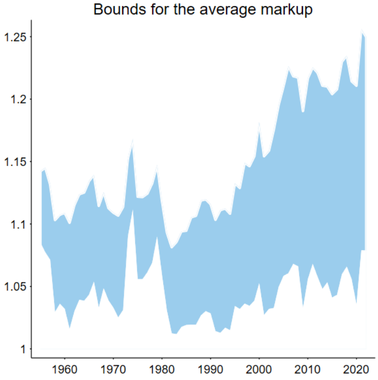
Cleaning

- We also consider two alternative cleaning procedures: the same as DLEU, and an enhanced procedure that additionally removes outliers in the SGA and PPE shares of sales, in the same way
- DLEU cleaning ($258,790$ obs):
  - remove duplicates and missing or negative sales, COGS, SGA, or PPE
  - drop the 1st and 99th percentiles of the COGS share of sales, separately for each year
- Enhanced cleaning ($248,995$ obs) is the same as DLEU cleaning, plus:
  - drop the 1st and 99th percentiles of the SGA, PPE, and imputed PPE expenditure shares of sales, separately for each year
- Our preferred sample uses the enhanced cleaning; all results are robust to using DLEU cleaning
- We deflate all values reported in dollars using the US GDP deflator, following DLEU; this only matters for weights, not for revenue shares

Revenue RTS and Price-Cost Markups

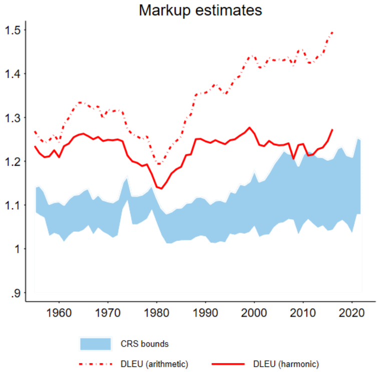
- Bounds for sales-weighted arithmetic mean of revenue RTS = sum of revenue elasticities for COGS, SGA, and PPE
- Implied bounds for sales-weighted harmonic mean of price-cost markups, assuming competitive input markets and CRS production technologies
- Widening gaps reflect increasing (within-sector) dispersion in revenue shares





Comparison with DLEU

- Sales-weighted arithmetic mean of estimated markups from the main DLEU specification is much higher, and increased more dramatically over this period
- The main reasons are:
  - arithmetic mean $>$ harmonic mean with markup dispersion
  - omission of SGA from the revenue production function specification

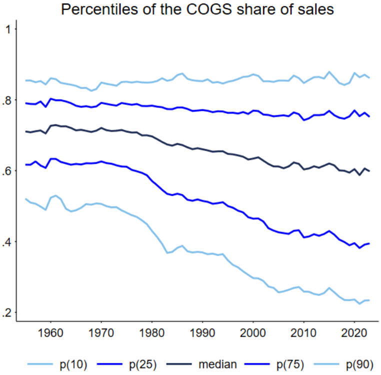


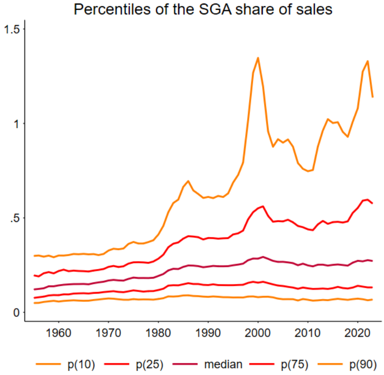
Some Additional Findings

- DLEU's estimates of output elasticities for COGS are very similar to pooled OLS and system GMM estimates of revenue elasticities for COGS, obtained from the same specification
- Weighted averages (across sectors) of those econometric estimates are much higher than our non-parametric upper bound for the corresponding weighted average revenue elasticity for COGS
- Weighted averages (across sectors) of econometric estimates of revenue RTS are:
  - close to one
  - stable over time
  - above our non-parametric upper bound
- Assuming competitive input markets and CRS production technologies, those estimates would imply little or no product market power
  - likely biased as a consequence of heterogeneous markups

Increasing Revenue Share Dispersion

- The generally widening gaps between our upper and lower bounds for average revenue RTS and thus markups are driven by an increase in the cross-section dispersion of revenue shares





- This may reflect an increase in the dispersion of markups and/or an increase in the dispersion of output elasticities

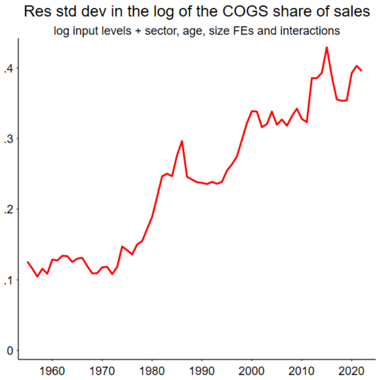
Increasing Markup Dispersion

- If COGS is a flexible input and technology parameters are common, we can write the log sales share for COGS as

$$cogs_{it} - sales_{it} = \ln \beta_X(cogs_{it}, sga_{it}, ppe_{it}) - \ln \mu_{it} - m_{it}$$

  β_X is the output elasticity for COGS, which may depend on input levels

- Residual variance from annual regressions has an upward trend from the mid-1970s, consistent with an increase in markup dispersion



Summary

- We propose non-parametric bounds, implied by profit-maximisation, for weighted arithmetic means of revenue elasticities, and revenue RTS, in a sample of firms
- Assuming competitive input markets and CRS production technologies, these imply bounds for weighted harmonic means of price-cost markups
  - appropriate measures of aggregate market power (Yeh et al., AER 2022; Edmond et al., JPE 2023)
- Our bounds for publicly traded North American firms suggest that the sales-weighted harmonic mean of price-cost markups evolved from an interval between 1.01-1.07 in the early 1980s to an interval between 1.08-1.24 in 2022
  - suggesting that DLEU (QJE, 2020) over-estimate both the level of aggregate market power, and its rise
- The increase over time in the gap between our upper and lower bounds is consistent with a substantial increase in the cross-section dispersion of price-cost markups
  - consistent with the emergence of ‘superstar firms’ (Autor et al., QJE, 2020)

Extensions

- Sharper bounds may be available using clusters of firms with similar revenue shares, rather than firms in the same 2-digit sectors
- Approach could be used to study sectoral patterns in price-cost markups
- Approach could be applied to other company accounts datasets, and to census of production micro data (e.g. LRD)
- We may also be able to bound the variance of log markups, using the residual variance from specifications for the log revenue share for a flexible input
- Combined with our bounds for the harmonic mean of markups, that may allow bounds for other moments of the cross-section distribution of markups to be inferred
    - e.g. under a lognormality assumption