Production Approach Workshop@IDE-JETRO
Session 1

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Markup

- Price markup over marginal costs

$$\mu_{it} = \frac{P_{it}}{MC_{it}}$$

- A measure of firm's market power
  - Efficiency
  - Income distributions

Production Approach to Markup Estimation

- A traditional approach to estimating markups is to estimate a demand function (demand approach)
- Recently, another "production" approach has become popular in trade and macroeconomics.
  - Firm-level production data on output and inputs
  - De Loecker and Warzynski (2012)(1880 google citations)
- Discrepancy between theory and applications
  - Theory: firm-level data on output quantity
  - Many applications: data on revenue, not quantity
  - Non-identification of markup with revenue data: Bond, Hashemi, Kaplan and Zoch (2020)

Agenda

- Session 1: Production Approach with Output Quantity Data
- Session 2: Production Approach with Revenue Data: Kasahara and Sugita (2023)
- Session 3: Estimation Codes of Kasahara and Sugita (2023)

Markup

- Firm's maximization problem

$$\min_{Y_{it}} P_t\left(Y_{it}, z_{it}\right) Y_{it} - C_t(Y_{it})$$

z_{it} : vector of demand shifters

- FOC leads to markup formula

$$\mu_{it} = \frac{P_{it}}{MC_{it}} = \left(1 - \frac{1}{\epsilon_{it}^D}\right)$$

where $\epsilon_{it}^D \equiv -\left(\frac{\partial P_t}{\partial Y_{it}} \frac{Y_{it}}{P_{it}}\right)^{-1}$: demand elasticity

Demand Approach

- Estimate a demand system and a demand elasticity ϵ_{it}^{D} under oligopoly
    - Berry, Levinsohn and Pakes (1995); Gandhi and Nevo (2021)(survey)
- Requirement
    - Data on price and quantity sold in many markets
    - Instrument variable for price
    - Specify the functional form of the demand function
    - Specify the market structure (e.g. Bertrand competition)

Production Approach

- A firm produces a good by using material M_{it}, capital K_{it}, and labor L_{it}:
$$Y_{it} = F_{it}(M_{it}, K_{it}, L_{it})$$
- M_{it}: flexible input (no adjustment cost) and perfect competition
- K_{it}, L_{it}: determined at $t-1$

Production Approach

- Firm i chooses material M_{it} given (K_{it}, L_{it}, Y_{it}) to minimize its cost:

$$C_{it}(K_{it}, L_{it}, Y_{it}) \equiv \min_{M_{it}} P_t^M M_{it}$$
$$\text{s.t.}\, Y_{it} \leq F_{it}\left(M_{it}, K_{it}, L_{it}\right)$$

- FOC

$$P_t^M = \lambda_{it} \frac{\partial F_{it}}{\partial M_{it}}$$

where the Lagrange multiplier is

$$\lambda_{it} = \frac{\partial C_{it}(K_{it}, L_{it}, Y_{it})}{\partial Y_{it}} = MC_{it}$$

Production Approach

- Price markup over marginal cost

$$\frac{P_{it}}{\lambda_{it}} = \frac{\partial F_{it}}{\partial M_{it}} \frac{P_{it}}{P_t^M} = \frac{\partial F_{it}}{\partial M_{it}} \frac{M_{it}}{Y_{it}} \frac{P_{it} Y_{it}}{P_t^M M_{it}}$$

- Markup formula

$$\mu_{it} = \frac{P_{it}}{\lambda_{it}} = \frac{\theta_{it}^M}{\alpha_{it}^M}$$

where

$$\theta_{it}^M \equiv \frac{\partial F_{it}}{\partial M_{it}} \frac{M_{it}}{Y_{it}} : \text{material elasticity}$$

$$\alpha_{it}^M \equiv \frac{P_t^M M_{it}}{P_{it} Y_{it}} : \text{ material expenditure share in revenue}$$

Production Approach to Markup Estimation

- Estimate a production function F_{it}, calculate a material elasticity θ_{it}^{M} and α_{it}^{M} in data
- Requirement
  - Production data: output and inputs, short panel data
  - Assumptions for production function estimation

Constant Material Elasticity Case

- E.g., Cobb-Douglas production function

$$\theta_{it}^{M} = b$$

- $1/\alpha_{it}^{M}$ itself identifies markup up to scale.

$$\frac{1}{\alpha_{it}^{M}} = \frac{\mu_{it}}{b}$$

- Relative markups can be identified

$$\frac{\mu_{it}}{\mu_{jt}} = \frac{\alpha_{jt}^{M}}{\alpha_{it}^{M}} \text{ and } \frac{\mu_{it}}{\mu_{it-1}} = \frac{\alpha_{it-1}^{M}}{\alpha_{it}^{M}}.$$

Constant Material Elasticity Case

- β: causal impact of X on a markup change can be identified:

$$\ln \mu_{it} = \alpha + \beta X_{it} + \epsilon_{it}$$
$$\Rightarrow \ln \frac{1}{\alpha^M_{it}} = (\alpha - b) + \beta X_{it} + \epsilon_{it}$$

Application: Marginal Cost

- We can estimate marginal costs with price data: $MC_{it} = P_{it}/\mu_{it}$
  - Price pass-through of tariffs on inputs (De Loecker, Goldberg, Khandelwal and Pavcnik, 2016)

Application: Wage Markdown

- $w_{it}(L_{it})$: inverse labor supply curve for firm i

$$\max_{L_i, M_{it}} R_{it}(Y_{it}) - w_{it}(L_{it})L_{it} - P_{it}^{M} M_{it}$$
$$\text{s.t.}\, Y_{it} = F_{it}(M_{it}, L_{it}, K_{it})$$

- FOCs

$$\frac{\partial R_{it}}{\partial Y_{it}} \frac{\partial F_{it}}{\partial M_{it}} = P_{it}^{M}$$
$$\frac{\partial R_{it}}{\partial Y_{it}} \frac{\partial F_{it}}{\partial L_{it}} = w_{it}\left(1 + \frac{1}{\epsilon_{it}^{LS}}\right)$$

Application: Wage Markdown

- Wage markdown (Lu, Sugita and Zhu (2019))

$$
\begin{aligned}
\eta_{it} = \frac{w_{it}}{\frac{\partial R_{it}}{\partial Y_{it}} \frac{\partial F_{it}}{\partial L_{it}}} &= \frac{w_{it}}{P^M_{it}} \frac{\frac{\partial F_{it}}{\partial M_{it}}}{\frac{\partial F_{it}}{\partial L_{it}}} \\
&= \frac{w_{it} L_i}{P^M_{it} M_{it}} \frac{\frac{\partial F_{it}}{\partial M_{it}} \frac{M_{it}}{Y_{it}}}{\frac{\partial F_{it}}{\partial L_{it}} \frac{L_{it}}{Y_{it}}} \\
&= \frac{\alpha^L_{it}}{\alpha^M_{it}} \frac{\theta^M_{it}}{\theta^L_{it}}
\end{aligned}
$$

Application: Labor Share

- Labor share in value-added (Lu, Sugita and Zhu (2019))

$$\begin{aligned}
\frac{w_{it} L_{it}}{VA_{it}} &= \alpha_{it}^{L} \left(\frac{R_{it}}{VA_{it}} \right) \\
&= \left(\frac{\frac{\alpha_{it}^{L}}{\alpha_{it}^{M}} \frac{\theta_{it}^{M}}{\theta_{it}^{L}}}{\frac{\theta_{it}^{M}}{\alpha_{it}^{M}}} \right) \theta_{it}^{L} \left(\frac{R_{it}}{VA_{it}} \right) \\
&= \left(\frac{\text{wage markdon}_{it}}{\text{price markup}_{it}} \right) \theta_{it}^{L} \left(\frac{R_{it}}{VA_{it}} \right)
\end{aligned}$$

Production Function Estimation with Quantity data

- Production data
  - Y_{it}: output
  - (M_{it}, K_{it}, L_{it}): inputs (materials, capital, labor)
  - (Short) panel data
- Single product firm
- Notation
  - $y_{it} = \ln Y_{it}$,$m_{it} = \ln M_{it}$,$l_{it} = \ln L_{it}$

Setting

- Inverse demand for firm i

$$\begin{aligned} p_{it} &= \psi\left(y_{it}, z_{it}^{d}, a_t\right) \\ &= \psi_t\left(y_{it}, z_{it}^{d}\right) \end{aligned}$$

- z_{it}^{d}: firm-level demand shifters
  - In an oligopoly setting, z_{it} should include other firms' choice variables (price in Bertrand, quantity in Cournot)
  - Demand shocks, quality difference, etc.
- a_t: industry-level demand shifters that the firm
  - E.g., market size; aggregate price (quantity) index under monopolistic competition

Input Endogeneity

- Log production function with total factor productivity (TFP) ω

$$y_{it} = f\left(m_{it}, k_{it}, l_{it}\right) + \omega_{it}$$

- Input endogeneity
  - (m_{it}, k_{it}, l_{it}) are correlated with ω_{it}
  - With persistent ω_{it}, past inputs $(m_{it-1}, k_{it-1}, l_{it-1})$ are correlated with ω_{it}

Dynamic panel approach

- Arellano and Bond (1991); Arellano and Bover (1995); Blundell and Bond (1998, 2000)
    - Olley and Pakes (1996); Levinsohn and Petrin (2003); Ackerberg et al. (2015)
- Model a dynamic process of (persistent) ω_{it}, e.g., first order Markov process:

$$\omega_{it} = h(\omega_{it-1}) + \eta_{it}$$

    - $\eta_{it} \sim G_\eta$: i.i.d. shock
    - h may include control variables (e.g., ownership; past export status; past R&D investment)

Dynamic panel approach

- Production function

$$
\begin{aligned}
y_{it} &= f\left(m_{it}, k_{it}, l_{it}\right) + h(\omega_{it-1}) + \eta_{it} \\
&= f\left(m_{it}, k_{it}, l_{it}\right) + h\left[y_{it-1} - f\left(m_{it-1}, k_{it-1}, l_{it-1}\right)\right] + \eta_{it}
\end{aligned}
$$

- Search for variables uncorrelated with η_{it} instead of ω_{it}

Dynamic panel approach

- Predetermined variables
  - $(y_{it-1}, m_{it-1}, k_{it-1}, l_{it-1})$ are determined at $t-1$ and uncorrelated with η_{it}
  - k_{it} and l_{it} are often assumed to be determined at $t-1$ because of adjustment costs.
- m_{it} is a main endogenous variable correlated with η_{it}
  - m_{it-s} $(s = 2, ...)$ may be used for an IV for m_{it} under certain conditions.

Control function approach

- Profit maximization

$$\max_{m} \exp\left(p_t + y_{it}\right) - \exp\left(p_t^m + m_{it}\right)$$
$$\text{s.t. } \; y_{it} = f\left(m_{it}, k_{it}, l_{it}\right) + \omega_{it}$$
$$p_{it} = \psi_t\left(y_{it}, z_{it}^d\right)$$

- Material demand function

$$m_{it} = \mathbb{M}_t\left(\omega_{it}, k_{it}, l_{it}, z_{it}^d\right)$$

Proxy variable approach

- Assume $\mathbb{M}_t\left(\omega_{it}, k_{it}, l_{it}\right)$ is increasing in ω_{it} and take its inverse:

$$\omega_{it} = \mathbb{M}_t^{-1}\left(m_{it}, k_{it}, l_{it}, z_{it}^d\right)$$

  - A (unknown) function of inputs and demand shifters may control for productivity
- Proxy variable (control function) approach
  - Early studies ((Olley and Pakes, 1996; Levinsohn and Petrin, 2003)) aimed to use this idea to identify some parameters of f.
  - Ackerberg, Caves and Frazer (2015): not possible except special circumstances.

Proxy variable approach

- Production function

$$\begin{aligned} y_{it} &= f\left(m_{it}, k_{it}, l_{it}\right) + \mathbb{M}_t^{-1}\left(m_{it}, k_{it}, l_{it}, z_{it}^d\right) \\ &= \phi_t\left(m_{it}, k_{it}, l_{it}, z_{it}^d\right) \end{aligned}$$

- We can only identify $\phi_t\left(m_{it}, k_{it}, l_{it}, z_{it}\right)$ but not $f\left(m_{it}, k_{it}, l_{it}\right)$ separately.

De Loecker and Warzynski (2012)(DLW)

- Step1: Remove a measurement error ϵ_{it} in y_{it} (Ackerberg et al., 2015)

$$\begin{aligned} y_{it}^{Data} &= y_{it} + \epsilon_{it} \\ &= \phi_t \left(m_{it}, k_{it}, l_{it}, z_{it}^d \right) + \epsilon_{it} \end{aligned}$$

- Step2: identify a production function

$$y_{it} = f\left(m_{it}, k_{it}, l_{it}\right) + h\left[y_{it-1} - f\left(m_{it-1}, k_{it-1}, l_{it-1}\right)\right] + \eta_{it}$$

by using past m_{it-s} as an IV for m_{it}

Discussion

- Myth: "no need to specify the demand function and the market structure"
  - True only if z_{it} includes all demand shifters and all rival firms' choice variables, which is impossible.
  - No unobserved demand shocks
- De Loecker and Warzynski (2012)

$$\mathbb{M}_t^{-1}\left(m_{it}, k_{it}, wage_{it}, export_{it}\right)$$

  - Implicitly assumption: monopolistic competition with a demand function

$$p_{it} = \psi_t(y_{it}, export_{it})$$

Discussion

- In many applications, z_{it} is not included.

$$\omega_{it} = \mathbb{M}_t^{-1}\left(m_{it}, k_{it}, l_{it}\right)$$

- Gandhi, Navarro and Rivers (2020)(GNR): m_{it-1} is a weak instrument for m_{it}:

$$\begin{aligned} m_{it} &= \mathbb{M}_t\left(\omega_{it}, k_{it}, l_{it}\right) \\ &= \mathbb{M}_t\left(h(\omega_{it-1}) + \eta_{it}, k_{it}, l_{it}\right) \\ &= \mathbb{M}_t\left(h\left(y_{it-1} - f\left(m_{it-1}, k_{it-1}, l_{it-1}\right)\right) + \eta_{it}, k_{it}, l_{it}\right). \end{aligned}$$

- When $\left(k_{it}, l_{it}, y_{it-1}, m_{it-1}, k_{it-1}, l_{it-1}\right)$ are conditioned, m_{it-2} cannot affect m_{it}.

Discussion

- Suppose another variable w_{it} affects the material demand

$$
\begin{aligned}
m_{it} &= \mathbb{M}\left(\omega_{it}, k_{it}, l_{it}, w_{it}\right) \\
&= \mathbb{M}_t\left(h\left(y_{it-1} - f\left(m_{it-1}, k_{it-1}, l_{it-1}\right)\right) + \eta_{it}, k_{it}, l_{it}, w_{it}\right).
\end{aligned}
$$

- If w_{it} is correlated with w_{it-2}, then m_{it-2} may correlate with m_{it}.
    - E.g., demand shifters z_{it}^d; material price p_{it}^m that varies across firms
    - w_{it} may be unobservable
- Note: to use $\mathbb{M}_t^{-1}\left(m_{it}, k_{it}, l_{it}, w_{it}\right)$ in step 1, all w_{it} must be observable and uncorrelated with η_{it}.

Address the GNR critique

- Three approaches are proposed to address the GNR critique.
- They all transforms the problem into

$$y_{it} = g\left(k_{it}, l_{it}\right) + h\left[y_{it-1} - g\left(k_{it-1}, l_{it-1}\right)\right] + \eta_{it},$$

which has no endogeneous variable.

Ackerberg, Caves and Frazer (2015)

- Ackerberg, Caves and Frazer (2015) consider a structural value-added function
$$y_{it} = \min\left\{c(m_{it}), g(k_{it}, l_{it}) + \omega_{it}\right\},$$
which implies
$$y_{it} = g(k_{it}, l_{it}) + \omega_{it}.$$
- However, this production function is not differentiable with respect to m_{it}.

Gandhi, Navarro and Rivers (2020)

- FOC for material under perfect competition

$$\alpha_{it}^{m} = \frac{\partial f}{\partial m}(m_{it}, k_{it}, l_{it})$$

- Identify $\frac{\partial f}{\partial m}(m_{it}, k_{it}, l_{it})$ from regression of α_{it}^{m} on (m_{it}, k_{it}, l_{it}).
    - They also analyze imperfect competition but assume a common markup μ_t

Gandhi, Navarro and Rivers (2020)

- Integrate

$$f(m_{it}, k_{it}, l_{it}) = f(m_0, k_{it}, l_{it}) + \int_{m_0}^{m_{it}} \frac{\partial f}{\partial m}(m, k_{it}, l_{it})dm$$
$$\equiv g(k_{it}, l_{it}) + \int_{m_0}^{m_{it}} \alpha^m(m, k_{it}, l_{it})dm$$

- Defining $\mathcal{Y}_{it} \equiv y_{it} - \int_{m_0}^{m_{it}} \alpha^m(m, k_{it}, l_{it})dm$, we have

$$\mathcal{Y}_{it} = g(k_{it}, l_{it}) + \omega_{it}$$

Flynn, Gandhi and Traina (2019)

- Flynn, Gandhi and Traina (2019) proposes imposing constant returns to scale.
- E.g., Cobb-Douglas case

$$
\begin{aligned}
y_{it} &= (1 - \theta_k - \theta_l)\, m_{it} + \theta_k k_{it} + \theta_l l_{it} + \omega_{it} \\
y_{it} - m_{it} &= \theta_k \left(k_{it} - m_{it}\right) + \theta_l \left(l_{it} - m_{it}\right) + \omega_{it}
\end{aligned}
$$

- Define $\tilde{y}_{it} \equiv y_{it} - m_{it}$, $\tilde{k}_{it} \equiv k_{it} - m_{it}, \tilde{\ }_{it} \equiv y_{it} - m_{it}$,

$$
\tilde{y}_{it} = \theta_k \tilde{k}_{it} + \theta_l \tilde{l}_{it} + \omega_{it}
$$

- They also analyze general production functions.

Production approach with quantity data

- Approach 1: DLW approach with Flynn, Gandhi and Traina (2019) in Step 2
  - Assume constant returns to scale.
  - Step1 is the same as DLW: to remove the measurement error in y_{it}
  - Step 2 estimate as Flynn, Gandhi and Traina (2019).
- Step 1 implicitly specifies the market structure and the demand function

Production approach with quantity data

- Approach 2: dynamic panel approach (or DLW approach without step 1)
  - Assume no measurement error in y_{it}^{Data} as for other variables
  - Assume some unobserved and serially correlated w_{it} that correlates with m_{it}
  - Past m_{it-2} can be used for an IV
- Weaker assumptions on the market structure and the demand function

Issues

- Multi-product firms
  - Output quantity may be observed at product-level, but inputs are rarely observed at product-level.
  - De Loecker, Goldberg, Khandelwal and Pavcnik (2016); Orr (2022)
- Labor- and capital-augmenting productivity
  - Automation, PC, AI, etc.
  - Demirer (2022)
- Quality
  - Production of high quality products sometimes require more inputs than that of low quality products.
  - Orr (2022)

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