Micro Data for Macro Models

Topic 1: Productivity Dispersion, Aggregation, and Misallocation

Thomas Winberry

January 7th, 2019
Plan for this Topic

1. Document large and persistent dispersion of firms’ productivity

2. Show benchmark irrelevance result: without frictions to inputs, economy still has representative firm

3. Measure input frictions using reduced form “misallocation” measures
   - Substantial frictions at micro-level
   - Implies large differences in the aggregate
1. **Document large and persistent dispersion of firms’ productivity**

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Definitions of Productivity

• Productivity is the amount of **output produced per unit of inputs**

• Depends on unit of analysis:
  1. **Establishment**: A business or production unit at a single location
  2. **Firm**: A collection of establishments under common legal control

• Depends on input:
  1. **Labor productivity**: output per labor input \( \frac{y_{it}}{n_{it}} \)
  2. **Capital productivity**: output per capital input \( \frac{y_{it}}{K_{it}} \)
  3. **Total factor productivity**: output per composite of inputs
     \[
     \frac{y_{it}}{k_{it}^\alpha n_{it}^{1-\alpha}}
     \]
What Is Productivity?

- Productivity is **anything that influences output other than measured inputs**
  - A useful measure of our ignorance

- What could it be?
  1. Technology
  2. Efficiency
  3. Managerial skill
  4. Market conditions
  5. Regulation
  6. Utilization
Measuring Productivity in Practice

\[ z_{it} = \log(y_{it}) - \alpha \log(k_{it}) - (1 - \alpha) \log(n_{it}) \]
Measuring Productivity in Practice

\[ z_{it} = \log(y_{it}) - \alpha \log(k_{it}) - (1 - \alpha) \log(n_{it}) \]

1. **Estimate output elasticity** \(\alpha\)
   - Factor shares method: with Cobb-Douglas and perfect competition, \(1 - \alpha = \) labor share
   - Production function estimation: have to deal with endogeneity problem
Measuring Productivity in Practice

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1. **Estimate output elasticity \( \alpha \)**
   - Factor shares method: with Cobb-Douglas and perfect competition, \( 1 - \alpha = \) labor share
   - Production function estimation: have to deal with endogeneity problem

2. **Construct measures of \( y_{it}, k_{it}, \) and \( n_{it} \)**
   - \( y_{it} \): usually gross output (sales) or value added (sales - materials)
   - \( k_{it} \): book value, replacement value, perpetual inventory
   - \( n_{it} \): number of workers, hours worked, wage bill
Stylized Facts About Productivity (Syverson 2011)

1. **Enormous dispersion across establishments, even within narrowly-defined sector**
   - Within average sector, 90th percentile firm is 2 times as productive as 10th
   - SD of this range across sectors is 0.17
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2. **Productivity is persistent**
   - Annual autocorrelation 0.6 - 0.8
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2. **Productivity is persistent**
   - Annual autocorrelation 0.6 - 0.8

3. **Productivity matters**
   - Correlated with outcomes like hiring, investment, survival
A Case Study: Castro, Clementi, and Lee (2015)

- A nice illustration of computing TFP using Census data: Annual Survey of Manufactures (ASM)
  - Standard data source for computing productivity (main alternative is Compustat)
  - Confidential; need approved project proposal

- Advantages
  - Measures of output, labor, and capital
  - Panel dimension allows for fixed-effect analysis
  - Long time sample: since late 1970s

- Disadvantages
  - Only covers manufacturing, a declining share of economy
  - Measurement error a potential problem
Variable Definitions and Measurement

\[ z_{ist} = \log(y_{ist}) - \alpha^k_{st} \log(k_{ist}) - \alpha^n_{st} \log(n_{ist}) - \alpha^m_{st} \log(m_{ist}) \]

• Output \( y_{ist} \): gross revenue divided by 4-digit SIC price deflator from NBER

• Capital \( k_{ist} \): constructed using perpetual inventory method
  \[ k_{is0} = \text{book value}, \quad k_{ist+1} = (1 - \delta_{st})k_{ist} + \frac{i_{ist}}{p^i_{st}} \]

• \( i_{ist} \): total capital expenditures
• \( \delta_{st} \): 2-digit depreciation rates from BEA
• \( p^i_{st} \): 4-digit investment price deflator from NBER
**Variable Definitions and Measurement**

\[ z_{ist} = \log(y_{ist}) - \alpha^k_{st} \log(k_{ist}) - \alpha^n_{st} \log(n_{ist}) - \alpha^m_{st} \log(m_{ist}) \]

- **Labor** \( n_{ist} \): total hours of production and nonproduction workers
  \[ n_{ist} = \text{hours}^{\text{prod}}_{ist} + \frac{\text{wage bill}^{\text{nonprod}}_{ist}}{\text{wage bill}^{\text{prod}}_{ist}} \cdot \text{hours}^{\text{prod}}_{ist} \]

- **Materials** \( m_{ist} \): total materials cost deflated by 4-digit deflator from NBER

- **Labor and material elasticities** \( \alpha^n_{st} \) and \( \alpha^m_{st} \): revenue shares at 4-digit sector
  - **Capital elasticity** \( \alpha^k_{st} \): \( \alpha^k_{st} = 1 - \alpha^n_{st} - \alpha^m_{st} \)
Shocks to TFP

\[ z_{ist} = \mu_i + \mu_{st} + \rho_s z_{ist-1} + \beta_s \log(\text{size})_{ist} + \sum_{j=1}^{3} \psi_{sj} D_{istj} + \epsilon_{ist} \]

where

- Firm fixed effect \( \mu_i \)
- Sector-time fixed effect \( \mu_{st} \)
- Autocorrelation by sector \( \rho_s \)
- Size by industry \( \beta_s \)
- Plant age effects \( D_{istj} \)

The residual \( \epsilon_{ist} \) is the unforecastable shock to TFP.
Shocks to TFP

About 80% of total variation in $\varepsilon_{ist}$ is specific to the establishment
→ Most volatility is micro volatility!
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   - Substantial frictions at micro-level
   - Implies large aggregate effects
Aggregation with Productivity Dispersion

Consider production side of economy in time $t$ with:

- **Heterogeneous firms** $i \in [0, 1]$ with production function
  \[ y_{it} = e^{z_{it} k_{it}^{\alpha_k} n_{it}^{\alpha_n}}, \alpha_k + \alpha_n \leq 1 \]

- **Perfect competition** in factor markets
  - Rent capital at rate $r_t$
  - Hire labor at rate $w_t$
Aggregation with Productivity Dispersion

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Can we represent this structure with an aggregate production function?

\[
Y_t = e^{Z_t} F(K_t, N_t) \text{ where } K_t = \int k_{it} di, \quad N_t = \int n_{it} di, \text{ and } Y_t = \int y_{it} di
\]
Decreasing Returns, $\alpha_k + \alpha_n < 1$

Claim: aggregates $Y_t$, $K_t$, and $N_t$ are same with representative firm

$$Y_t = e^{Z_t} K_t^{\alpha_k} N_t^{\alpha_n} \text{ with } Z_t = \log \left( \int (e^{zt})^{\frac{1}{1-\alpha_k-\alpha_n}} \right)$$
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- First order conditions for profit maximization of firm $i$:

$$\alpha_k e^{Z_{it}} k_{it}^{\alpha_k - 1} n_{it}^{\alpha_n} = r_t$$

$$\alpha_n e^{Z_{it}} k_{it}^{\alpha_k} n_{it}^{\alpha_n - 1} = w_t$$

$\rightarrow$ Firms equalize their marginal products
Decreasing Returns, $\alpha_k + \alpha_n < 1$

Claim: aggregates $Y_t$, $K_t$, and $N_t$ are same with representative firm

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- Manipulate the FOCs to get

$$k_{it} = \left(e^{Z_{it}}\right)^{\frac{1}{1-\alpha_k-\alpha_n}} \left(\frac{\alpha_k}{r_t}\right)^{\alpha_k} \left(\frac{\alpha_n}{W_t}\right)^{1-\alpha_k}$$

$$n_{it} = \left(e^{Z_{it}}\right)^{\frac{1}{1-\alpha_k-\alpha_n}} \left(\frac{\alpha_k}{r_t}\right)^{1-\alpha_n} \left(\frac{\alpha_n}{W_t}\right)^{\alpha_n}$$

$$y_{it} = \left(e^{Z_{it}}\right)^{\frac{1}{1-\alpha_k-\alpha_n}} \left(\frac{\alpha_k}{r_t}\right)^{\frac{\alpha_k}{1-\alpha_k-\alpha_n}} \left(\frac{\alpha_n}{W_t}\right)^{\frac{\alpha_n}{1-\alpha_k-\alpha_n}}$$
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- Aggregate to get

$$K_t = \int k_{it} di = e^{Z_t} \left( \frac{\alpha_k}{r_t} \right)^{\alpha_k} \left( \frac{\alpha_n}{W_t} \right)^{1-\alpha_k}$$

$$N_t = \int n_{it} di = e^{Z_t} \left( \frac{\alpha_k}{r_t} \right)^{1-\alpha_n} \left( \frac{\alpha_n}{W_t} \right)^{\alpha_n}$$

$$Y_t = \int y_{it} di = e^{Z_t} \left( \frac{\alpha_k}{r_t} \right)^{\frac{\alpha_k}{1-\alpha_k - \alpha_n}} \left( \frac{\alpha_n}{W_t} \right)^{\frac{\alpha_n}{1-\alpha_k - \alpha_n}}$$

→ Same choices as the representative firm!
Constant Returns, $\alpha_k + \alpha_n = 1$

Claim: aggregates $Y_t$, $K_t$, and $N_t$ are same with representative firm

$$Y_t = e^{Z_t} K_t^{\alpha_k} N_t^{\alpha_n} \text{ with } Z_t = \max_i Z_{it}$$
Constant Returns, $\alpha_k + \alpha_n = 1$

Claim: aggregates $Y_t$, $K_t$, and $N_t$ are same with representative firm

$$Y_t = e^{Z_t} K_t^{\alpha_k} N_t^{\alpha_n} \text{ with } Z_t = \max_i z_{it}$$

- With constant returns, scale of production not pinned down:

$$y_{it} = e^{z_{it}} \left( \frac{\alpha_k}{1 - \alpha_k} \frac{w_t}{r_t} \right)^{\alpha_k} n_{it}$$

→ wage must adjust so highest productivity firm indifferent
Constant Returns, $\alpha_k + \alpha_n = 1$

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- Need curvature in revenue function for non-degenerate size distribution
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   - Implies large aggregate effects
• Heterogeneous firms aggregate when they equalize their marginal products
  • All firms equivalent on the margin
Hsieh and Klenow (2009)

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- Misallocation literature asks:
  1. How disperse are marginal products across firms in the data?
     - Significant dispersion: SD ≈ 50%
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・Misallocation literature asks:
  1. How disperse are marginal products across firms in the data?
     ・Significant dispersion: $\text{SD} \approx 50\%$
  2. Do these differences matter for aggregate output?
     ・TFP gains from equalizing marginal products $\approx 75\%$
Hsieh and Klenow (2009)

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     - TFP gains from equalizing marginal products ≈ 75%

- Large differences across countries: TFP gains 40% in US vs. 130% in India

Consider production side of economy in time $t$ with:

- Heterogeneous firms $i$ produce differentiated good $y_i = e^{z_i k_i n_i}$
- Representative final good producer $Y_t = \left( \int y_i \right)$
- Firm $i$ is a monopolistic competitor with CES demand curve $(p_i P_t)$
- Alternative way to generate curvature in revenue function
- Idiosyncratic distortions to factor prices: $(\nu_i n_i \omega_t)$ and $(\nu_i k_i \rho_t)$
  - $n_i$: hiring costs, regulations, search frictions, ...
  - $k_i$: adjustment costs, financial constraints, ...

$\nu_i$

Consider production side of economy in time $t$ with:

- **Heterogeneous firms** $i \in [0, 1]$ produce differentiated good

$$y_{it} = e^{z_{it}} k_{it}^{\alpha} n_{it}^{\alpha}$$

Consider production side of economy in time $t$ with:

- **Heterogeneous firms** $i \in [0, 1]$ produce differentiated good
  \[ y_{it} = e^{z_{it}} k_{it}^{\alpha} n_{it}^{\alpha} \]

- **Representative final good producer** $Y_t = \left( \int y_{it}^{\frac{\sigma-1}{\sigma}} \, di \right)^{\frac{\sigma}{\sigma-1}}$

- Firm $i$ monopolistic competitor with **CES demand curve**
  \[ \left( \frac{p_{it}}{P_t} \right)^{-\sigma} Y_t \]

- **Alternative way to generate curvature** in revenue function

Consider production side of economy in time $t$ with:

- Heterogeneous firms $i \in [0, 1]$ produce differentiated good
  \[ y_{it} = e^{z_{it}} k_{it}^\alpha n_{it}^\alpha \]

- Representative final good producer $Y_t = \left( \int y_{it}^\frac{\sigma-1}{\sigma} \, di \right)^\frac{\sigma}{\sigma-1}$

- Firm $i$ monopolistic competitor with CES demand curve
  \[ \left( \frac{p_{it}}{P_t} \right)^{-\sigma} Y_t \]

- Alternative way to generate curvature in revenue function

- Idiosyncratic distortions to factor prices: $(1 + \tau_{it}^n)w_t$ and $(1 + \tau_{it}^k)r_t$
  - $\tau_{it}^n$: hiring costs, regulations, search frictions, ...
  - $\tau_{it}^k$: adjustment costs, financial constraints, ...
Firm Behavior Given Wedges

• Optimal input choices:

\[
\alpha \left( \frac{\sigma - 1}{\sigma} \right) \frac{p_{it}y_{it}}{k_{it}} = (1 + \tau^k_{it})r_t \\
\]

\[
(1 - \alpha) \left( \frac{\sigma - 1}{\sigma} \right) \frac{p_{it}y_{it}}{n_{it}} = (1 + \tau^n_{it})w_t \\
\]

\[
\rightarrow \tau^n_{it} \text{ and } \tau^k_{it}: \text{ how much firms do not equalize marginal products}
\]
Firm Behavior Given Wedges

• Optimal input choices:

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\alpha \left( \frac{\sigma - 1}{\sigma} \right) \frac{p_{it}y_{it}}{k_{it}} = (1 + \tau_{it}^k)r_t
\]

\[
(1 - \alpha) \left( \frac{\sigma - 1}{\sigma} \right) \frac{p_{it}y_{it}}{n_{it}} = (1 + \tau_{it}^n)w_t
\]

→ \( \tau_{it}^n \) and \( \tau_{it}^k \): how much firms do not equalize marginal products

• Output:

\[
y_{it} = \left( \frac{\sigma - 1}{\sigma} \right) \frac{e^{Z_{it}}}{\left( \frac{(1 + \tau_{it}^k)r_t}{\alpha} \right)^{\alpha} \left( \frac{(1 + \tau_{it}^n)w_t}{1 - \alpha} \right)^{1 - \alpha}}^{\sigma}
\]
Aggregation

• After a lot of algebra (don’t worry about it):

\[ Y_t = (T_t^p)^{\frac{\sigma}{\sigma-1}} (T_t^k)\alpha (T_t^n)^{1-\alpha} K_t^\alpha N_t^{1-\alpha}, \text{ where} \]

\[ T_t^p = \left( \int \left( \frac{(1 + \tau_{it}^k)^\alpha (1 + \tau_{it}^n)^{1-\alpha}}{e^{Z_{it}}} \right)^{1-\sigma} \frac{1}{\tau_{it}^n} \right)^{-1} \]

\[ T_t^n = \left( \int \left( \frac{(1 + \tau_{it}^k)^\alpha (1 + \tau_{it}^n)^{-\alpha}}{e^{Z_{it}}} \right)^{1-\sigma} \frac{1}{1 + \tau_{it}^n} \right)^{-1} \]

\[ T_t^k = \left( \int \left( \frac{(1 + \tau_{it}^k)^{\alpha-1} (1 + \tau_{it}^n)^{1-\alpha}}{e^{Z_{it}}} \right)^{1-\sigma} \frac{1}{1 + \tau_{it}^k} \right)^{-1} \]

• Compare distribution of wedges in data vs. no wedges

• K_t and N_t fixed! all maps into changes in aggregate TFP
Aggregation

• After a lot of algebra (don’t worry about it):

\[ Y_t = \left( T^p_t \right)^{\sigma-1} \left( T^k_t \right)^\alpha \left( T^n_t \right)^{1-\alpha} K^\alpha N_t^{1-\alpha}, \text{ where} \]

\[ T^p_t = \left( \int \left( \frac{(1 + \tau^k_{it})^\alpha (1 + \tau^n_{it})^{1-\alpha}}{e^{z_{it}}} \right)^{1-\sigma} di \right)^{-1} \]

\[ T^n_t = \left( \int \left( \frac{(1 + \tau^k_{it})^\alpha (1 + \tau^n_{it})^{-\alpha}}{e^{z_{it}}} \right)^{1-\sigma} \frac{1}{1 + \tau^n_{it}} di \right)^{-1} \]

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• Compare distribution of wedges in data vs. no wedges
Measuring Wedges and Productivity in the Data

\[
(1 + \tau_{it}^k) = \frac{\text{MRPK}_{it}}{r_t} = \frac{1}{r_t} \times \alpha \left( \frac{\sigma - 1}{\sigma} \right) \frac{p_{it}y_{it}}{k_{it}}
\]

\[
(1 + \tau_{it}^n) = \frac{\text{MRPL}_{it}}{w_t} = \frac{1}{w_t} \times (1 - \alpha) \left( \frac{\sigma - 1}{\sigma} \right) \frac{p_{it}y_{it}}{n_{it}}
\]

\[
e^{z_{it}} = \frac{y_{it}}{k_{it}^\alpha n_{it}^{1-\alpha}} = \left( \frac{p_{it}y_{it}}{k_{it}^\alpha n_{it}^{1-\alpha}} \right)^{\frac{\sigma - 1}{\sigma}}
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Measuring Wedges and Productivity in the Data

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\]

Want to infer wedges and productivity from data
Measuring Wedges and Productivity in the Data

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(1 + \tau_{it}^k) = \frac{\text{MRPK}_{it}}{r_t} = \frac{1}{r_t} \times \alpha \left( \frac{\sigma - 1}{\sigma} \right) \frac{p_{it}y_{it}}{k_{it}}
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\]

\[
e^{z_{it}} = \frac{y_{it}}{k_{it}^\alpha n_{it}^{1-\alpha}} = \frac{(p_{it}y_{it})^{\frac{\sigma-1}{\sigma}}}{k_{it}^\alpha n_{it}^{1-\alpha}}
\]

Plant level data from Census of Manufactures

- Revenue \( p_{it}y_{it} \) is nominal value added
- Capital \( k_{it} \) is book value of capital stock
- Labor \( n_{it} \) is wage bill of the plant
Measuring Wedges and Productivity in the Data

\[
(1 + \tau^k_{it}) = \frac{\text{MRPK}_{it}}{r_t} = \frac{1}{r_t} \times \alpha \left( \frac{\sigma - 1}{\sigma} \right) \frac{p_{it}y_{it}}{k_{it}}
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(1 + \tau^n_{it}) = \frac{\text{MRPL}_{it}}{w_t} = \frac{1}{w_t} \times (1 - \alpha) \left( \frac{\sigma - 1}{\sigma} \right) \frac{p_{it}y_{it}}{n_{it}}
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\[
e^{z_{it}} = \frac{y_{it}}{k_{it}^\alpha n_{it}^{1-\alpha}} = \left( \frac{p_{it}y_{it}}{k_{it}^\alpha n_{it}^{1-\alpha}} \right)^{\frac{\sigma-1}{\sigma}}
\]

Remaining quantities are calibrated

- Rental rate on capital \( r_t = 10\% \)
- Elasticity of substitution \( \sigma = 3 \)
- Capital share \( \alpha \) as 1 - labor share
- NB: actual implementation in paper complicated by sectoral heterogeneity
Dispersion in TFPQ in Line with Literature

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<th>2005</th>
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<td>164,971</td>
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Marginal Products Very Disperse

\[ \text{TFPR}_{it} = \frac{p_{it}y_{it}}{k_{it}^\alpha n_{it}^{1-\alpha}} = (\text{MPRK}_{it})^\alpha (\text{MRPL}_{it})^{1-\alpha} \]
Marginal Products More Disperse in India and China

<table>
<thead>
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<td>0.68</td>
<td>0.63</td>
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<td>75 – 25</td>
<td>0.97</td>
<td>0.88</td>
<td>0.82</td>
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<td>90 – 10</td>
<td>1.87</td>
<td>1.71</td>
<td>1.59</td>
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<tr>
<td>India</td>
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<tr>
<td>S.D.</td>
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<td>0.67</td>
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<td>75 – 25</td>
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<tr>
<td>90 – 10</td>
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Large Gains From Equalizing Marginal Products

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<th>2005</th>
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<td>95.8</td>
<td>86.6</td>
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<td>India %</td>
<td>1987</td>
<td>1991</td>
<td>1994</td>
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<tr>
<td>United States %</td>
<td>1977</td>
<td>1987</td>
<td>1997</td>
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<tr>
<td>United States %</td>
<td>36.1</td>
<td>30.7</td>
<td>42.9</td>
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Efficient vs. Actual Size Distribution

- China
- India
- United States
Takeaways From Topic 1

- Large dispersion in productivity across firms
  - Measurement involves many choices
  - But no matter how you do it, always large dispersion
Takeaways From Topic 1

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  - But no matter how you do it, always large dispersion

- Even with heterogeneity, representative firm exists if can adjust inputs frictionlessly
  - Firms equalize marginal products to factor prices
  - Every firm is the same on the margin

Misallocation literature provides evidence that the world is far away from a representative firm. Reduced-form wedges indicate firms are far away from equal marginal products. Dispersion in wedges matters for aggregate outcomes.
Takeaways From Topic 1

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  • Measurement involves many choices
  • But no matter how you do it, always large dispersion

• Even with heterogeneity, **representative firm exists if can adjust inputs frictionlessly**
  • Firms equalize marginal products to factor prices
  • Every firm is the same on the margin

• Misallocation literature provides **evidence that world is far away from representative firm**
  • Reduced-form wedges indicate firms far away from equal marginal products
  • Dispersion in wedges matters for aggregate outcomes

⇒ The rest of the course is figuring out what these wedges are
The Rest of the Course

**Topic 2: Investment and capital adjustment costs**

- Firms’ investment decisions are lumpy
- What kinds of frictions do we need to account for these patterns?
- What are the implications for aggregate dynamics?
- Aside: how do we solve models with heterogeneity?
The Rest of the Course

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**Topic 4: Entry, exit, and firms’ lifecycles**
- How do firms enter, grow, and die?
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