Scale-Biased Technical Change and Inequality

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- But technical change can also be scale-biased, i.e., shifts profits to larger firms
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  - And wages not the only source of income: business income is key for top inequality
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– But technical change can also be scale-biased, i.e., shifts profits to larger firms
  – And wages not the only source of income: business income is key for top inequality

Question: (how) does technical change affect inequality through scale bias?
Show that scale bias is important technological feature for inequality

Propose tractable framework to study the effects of scale-biased technical change

Empirically study effects of two of the most important GPTs in history

- **Steam engines** (large-scale-biased)
- **Electric motors** (small-scale-biased)
- **New data**: firm sizes, technology adoption and inequality (US and NL, 1850 – 1950)
Summary of findings

• **Theory:** scale-biased technical change and income inequality
  - technical change is large-scale-biased if it increases fixed costs sufficiently
  - large-scale-biased $\implies$ less entrepreneurship + larger firms + more inequality

• **Empirics:** test the theory using steam engines and electric motors
  - same purpose (converting energy into motion), but strong differences in scale bias
  - evidence confirms theoretical predictions
    1. steam engines (electric motors) increased (decreased) firm sizes
    2. steam engines (electric motors) increased (marginally decreased) inequality
    3. factory owners were main drivers of inequality effects (not workers)
Outline

1 Theory: scale-biased technical change and inequality

2 Scale bias in steam engines and electric motors

3 Empirics: testing the theory of scale-biased technical change

   Prediction 1: scale bias $\Rightarrow$ firm sizes

   Prediction 2: scale bias $\Rightarrow$ inequality

   Prediction 3: scale bias $\Rightarrow$ profit concentration $\Rightarrow$ inequality
Theory: the model visualized

Stage 1: Occupational choice

Stage 2: Entry decision

Stage 3: Technology adoption
trade off fixed and marginal cost

Stage 4: Profit maximization

Entrepreneur

Worker

Draw productivity $\psi$

Exit

Enter

$t_1$
$t_2 ... t_{J-1}$
$t_J$

$\pi_1(\psi)$ $\pi_2(\psi)$ .... $\pi_{J-1}(\psi)$ $\pi_J(\psi)$

Question: how does inequality depend on the technology set $T = \{t_1, ..., t_J\}$?
Theory: the model visualized

**Stage 1:** Occupational choice

**Stage 2:** Entry decision

**Stage 3:** Technology adoption
trade off fixed and marginal cost

**Stage 4:** Profit maximization

**Question:** how does inequality depend on the technology set $T = \{t_1, \ldots, t_J\}$?
Answer: inequality depends on scale bias in technology
Theory: scale-biased technical change and inequality

**Answer:** inequality depends on *scale bias* in technology

- **Definition:** technical change is *large-scale-biased* (small-scale-biased) iff it increases (decreases) the average fixed costs in the economy

- **Theoretical predictions:** if technical change is *large-scale-biased* it
  1. increases average firm size
  2. increases top income inequality
  3. increases inequality through profit concentration
Outline

1. Theory: scale-biased technical change and inequality

2. Scale bias in steam engines and electric motors

3. Empirics: testing the theory of scale-biased technical change
   - Prediction 1: scale bias $\implies$ firm sizes
   - Prediction 2: scale bias $\implies$ inequality
   - Prediction 3: scale bias $\implies$ profit concentration $\implies$ inequality
Comparing two technologies: steam engines and electric motors
Comparing two technologies: the fundamentals

<table>
<thead>
<tr>
<th>Features</th>
<th>Steam engines</th>
<th>Electric motors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed cost (50 hp, in unskilled wages)</td>
<td>3-4</td>
<td>0.02-0.04</td>
</tr>
<tr>
<td>Efficiency increases with size</td>
<td>Strongly</td>
<td>Barely</td>
</tr>
<tr>
<td>Source of power</td>
<td>Generated in plant</td>
<td>Purchased</td>
</tr>
<tr>
<td>Average capacity (US 1909, in hp)</td>
<td>93.4</td>
<td>8.5</td>
</tr>
</tbody>
</table>

**Large-scale-biased**  **Small-scale-biased**

Sources: own computation based on (Emery, 1883) (for steam engines) and (Bolton, 1926) (for electric motors).
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Prediction 1: scale bias \(\Rightarrow\) firm sizes

- **New data:** US Census of Manufactures, industry by state aggregates (1850-1950)
  - Number of establishments, employment, capital, production, value added, power usage
  - 51k state × industry × year observations

- **Method:** Instrumental variable diff-in-diff
  - Coal access \(\Rightarrow\) steam engines
  - Hydropower potential \(\Rightarrow\) electric motors

- **Result:** Large scale-biased technical change increases firm sizes ✓
Prediction 1: scale bias $\Rightarrow$ firm sizes

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Prediction 2: scale bias $\Rightarrow$ inequality

- **New data**: micro-level data on wealth-at-death from the Netherlands (1879-1927)
  - Digitized around 130,000 images with handwritten text recognition software
  - Hand-checked all individuals with large wealth (above 100k)
  - Covers half of population: around 1.5 million decedents, of which around 500k had wealth

- **Methods**: Difference-in-difference
  - Compare inequality in towns by adoption of steam engines and electric motors
  - Robust to IV: local pre-industrial (1816) exposure to steam engine/electric motors

- **Result**: Large scale-biased technical change increases inequality ✓

Steam engines:  
- Results OLS  
- Results IV

Electric motors:  
- Results OLS  
- Results IV
Prediction 2: scale bias $\implies$ inequality

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  - Compare inequality in towns by adoption of steam engines and electric motors
  - Robust to IV: local pre-industrial (1816) exposure to steam engine/electric motors

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Steam engines:
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- Results IV

Electric motors:
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- **Data:** zooming into major textile city of Enschede (1879-1927)
  - identify owners of textile factories

- **Method:** how much of inequality changes are driven by factory owners?
Results: inequality through scale bias, not skill bias

Including textile owners

Real Wealth at Death (1883 = 100)

1880 1885 1890 1895 1900 1905 1910 1915 1920

P0-P75 P75-P90 P90-P99 P99-P100
Results: inequality through scale bias, not skill bias
Conclusion

– Effect of technical change on inequality depends on its **scale bias**
  – *large-scale-biased* technical change: larger firms and more inequality
  – but opposite technologies also exist!
Conclusion

- Effect of technical change on inequality depends on its **scale bias**
  - large-scale-biased technical change: larger firms and more inequality
  - but opposite technologies also exist!
- Large-scale-biased technical change consistent with recent trends
  - decline in entrepreneurship rates (Salgado, ’20; Jiang & Sohail, ’23)
  - increase in firm concentration (Autor et al., ’17; Autor et al., ’20, Kwon et al., ’23)
  - entrepreneurial income accounts for most of the rise in income inequality (Smith et al., ’19)
Conclusion

- Effect of technical change on inequality depends on its **scale bias**
  - large-scale-biased technical change: larger firms and more inequality
  - but opposite technologies also exist!

- Large-scale-biased technical change consistent with recent trends
  - decline in entrepreneurship rates (Salgado, '20; Jiang & Sohail, '23)
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- Provides a framework to think about effects of ongoing technology adoption
Thank you!
Comparing two technologies: timing of adoption in the United States

- **Water**
- **Steam**
- **Internal combustion**
- **Purchased electricity**

HP per 100 employees
Comparing two technologies: average cost by capacity

Sources: own computation based on (Emery, 1883) (for steam engines) and (Bolton, 1926) (for electric motors).
Comparing two technologies: marginal cost by capacity

Sources: Own computation based on (Emery, 1883) (for steam engines) and (Bolton, 1926) (for electric motors).
Comparing two technologies: adoption rates by establishment size

(a) Steam engines (1880)

(b) Electric motors (1929)

Sources: samples from the Census of Manufactures. (Atack & Bateman, ’99) for 1880 and (Vickers & Ziebarth, ’23) for 1929.
Strategy: effect of steam engines on firm size

- Theory: steam engine adoption $\iff$ firm size

- Instrument: geographic variation in “coal access”
  - Definition: transportation-cost weighted access to coal resources (Donaldson & Hornbeck, '16)
  - Relevance: important determinant of coal prices and steam engine adoption
  - Exogeneity: made plausible by
    - using estimates of coal resources before the advent of mining
    - using estimates of transportation costs before the advent of railroads
  - Exclusion restriction: should not affect firm sizes other than through steam engine adoption
    - diagnostic check: estimating effects of coal on “placebo” industries
Strategy: reduced form effect of coal access on firm size

\[
\ln (y_{ist}) = \alpha_s + \eta_{it} + \sum_{t \in T} \beta_t \ln (\text{COAL}_s) \times 1[\text{Year} = t] + \lambda' X_{ist} + \varepsilon_{ist}
\]

where

- \(i, s, t\) index industry, state, and year, respectively
- \(y_{ist}\) is the average firm size in wage earners
- \(\text{COAL}_s\) denotes access to coal in state \(s\)
- vector of controls \(X_{ist}\) contains:
  - density of the population in state \(s\) at time \(t\)
  - interactions between \(t\) and hydropower potential and “market access” in state \(s\)
Results: reduced form effect of coal access on firm size

Standard errors are clustered on the state level. Confidence intervals are at the 95% confidence level.
Strategy: effect of electric motors on firm size

- Theory: electric motor adoption ↔ firm size
- Instrument: geographic variation in hydropower potential
  - Relevance: important determinant of electricity prices and adoption
  - Exogeneity: made plausible by using potential for —not realized — hydropower
  - Validity: should not affect firm sizes other than through electric motor adoption
    - explicitly control for market access through waterways
    - diagnostic check: estimating effect of hydropower potential on “placebo” industries
- Falsification test: should not estimate effects before ≈ 1900
Strategy: reduced form effect of hydropower on firm size

\[
\ln (y_{ist}) = \gamma_s + \eta_{it} + \sum_{t \in T} \beta_t \ln (HYDRO_s) \times \mathbb{1}[\text{Year} = t] + \lambda' X_{ist} + \varepsilon_{ist}
\]

where

- \(i, s, t\) index industry, state, and year, respectively
- \(y_{ist}\) is the average firm size in wage earners
- \(HYDRO_s\) denotes hydropower potential in state \(s\) in 1000’s of hp
- vector of controls \(X_{ist}\) contains:
  - density of the population in state \(s\) at time \(t\)
  - interactions between \(t\) and coal access and “market access” in state \(s\)
Standard errors are clustered on the state level. Confidence intervals are at the 95% confidence level.
Hydropower potential in the US

- More than 5,000,000 hp
- 1,000,000 to 5,000,000 hp
- 500,000 to 1,000,000 hp
- 0 to 500,000 hp
Definition of coal access

- Analagous to “market access” approach by (Donaldson & Hornbeck, '16)

- Coal access for county $c$ in state $s$ as

$$\text{COAL}_c^s = \sum_o \tau_{oc}^{-\theta} \text{BTU}_o$$

where

- $\tau_{oc} \geq 1$ is the “iceberg cost” of transporting coal between counties $o$ and $c$ in 1830 (Donaldson & Hornbeck, '16)

- $\theta = 8.22$ is the trade elasticity (Donaldson & Hornbeck, '16)

- Coal access on the state-level is the average coal access of all counties in the state
Electricity prices and hydropower potential

Electricity price ($/KwH, 1929)

Hydropower potential (in logs of KwH)

\[ q = -0.557 \]
Coal prices and resources

\( \rho = -0.583 \)
## First stage: hydropower potential $\rightarrow$ purchased electric energy use

<table>
<thead>
<tr>
<th></th>
<th>MwH per employee</th>
<th>Electricity as share of fuel costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydropower potential</td>
<td>0.659*** (0.175)</td>
<td>0.020*** (0.004)</td>
</tr>
<tr>
<td></td>
<td>0.654*** (0.191)</td>
<td>0.019*** (0.005)</td>
</tr>
<tr>
<td></td>
<td>0.646*** (0.194)</td>
<td>0.017*** (0.004)</td>
</tr>
<tr>
<td>Coal resources</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Firm size</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Observations</td>
<td>5029</td>
<td>5008</td>
</tr>
</tbody>
</table>

Standard errors in parentheses are clustered at the state-level. Industry fixed-effects included.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. 
First stage: coal resources $\rightarrow$ steam engine adoption

<table>
<thead>
<tr>
<th></th>
<th>Steam HP per employee (asinh)</th>
<th>Steam as share of total HP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal access (logs)</td>
<td>0.027*** (0.005)</td>
<td>0.027*** (0.004)</td>
</tr>
<tr>
<td>Hydro-potential</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Firm size</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Observations</td>
<td>3890</td>
<td>3890</td>
</tr>
</tbody>
</table>

Standard errors in parentheses are clustered at the state-level. Industry fixed-effects included.

* $p<0.10$, ** $p<0.05$, *** $p<0.01$.  

Back
Results: heterogeneous effects of coal access

(a) Adopting industries
(b) Placebo industries

Bars represent 95% confidence intervals. Standard errors are clustered at the state-level. Placebo-industries are those in the bottom quartile in terms of steam engine horsepower per employee in 1890 nationally.
Results: heterogeneous effects of hydropower potential

(a) Adopting industries

(b) Placebo industries

Bars represent 95% confidence intervals. Standard errors are clustered at the state-level. Placebo-industries are those in the bottom quartile in terms of steam engine horsepower per employee in 1890 nationally.
Digitized: Micro-level data on wealth (NL, 1879 - 1927)
Strategy: effect of steam engines and electric motors on inequality
Strategy IV: effect of steam engines on inequality
Results: effect of *steam engines* on inequality
Results IV: effect of **steam engines** on inequality
Strategy: effect of electric motors on inequality
Strategy IV: effect of electric motors on inequality
Results: effect of electric motors on inequality
Results IV: effect of electric motors on inequality
Namelist textile merchants Enschede (1795)

Jan van Lochem
Pieter ter Kuile
De Erven Herman van Lochem
Laarander en Ton Tuy en Comp.
De Wed. Jochem Nieuwenhuis
H. en J. Roosling
Jan Blijdenstein en Zoon
Engbert ter Kuile
Jan Beukers
Hoochmaker en Comp.
Barend Leurink
Claes ten Cate
Barend Kramer
Arend Coster en Comp.
Maurits Elderink
Lambert Coster
Jan Coster
H. Wennink en Kuijte
Hendriks Pennink
Hendrik ten Cate
Saalomon ten Cate
Wed. Antony Hartgerink
Jacob ter Meulen
Jan Rierink en Zoon in Bombazynen in zoortien en Marcellates als voren.

Deze fabriceren alle soorten van gekoperde en ongekoperde Bombazynen, Katogene baatijen, en Marcellas, als mede zonnige Els-werktjes en Diemen &c. &c.

Zynde alle deze Fabriekwaarten, byzonder de Bombazyn, veel beter van deugd en kvaliteit dan de Beckholtsche en Warenbeper buitenlandische of Dutchtchen.