Scale-Biased Technical Change and Inequality

Hugo Reichardt
London School of Economics

September 29, 2023

Scale-Biased Technical Change and Inequality

- Dominant view: if technical change is **skill**-biased, wage inequality increases

Scale-Biased Technical Change and Inequality

- Dominant view: if technical change is **skill**-biased, wage inequality increases
- But technical change can also be **scale**-biased, i.e., shifts profits to larger firms

Scale-Biased Technical Change and Inequality

- Dominant view: if technical change is **skill**-biased, wage inequality increases
- 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

Scale-Biased Technical Change and Inequality

- Dominant view: if technical change is **skill**-biased, wage inequality increases
- 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?

This paper: Scale-biased technical change and inequality

1. Show that **scale bias** is important technological feature for inequality
2. Propose tractable framework to study the effects of scale-biased technical change
3. 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)

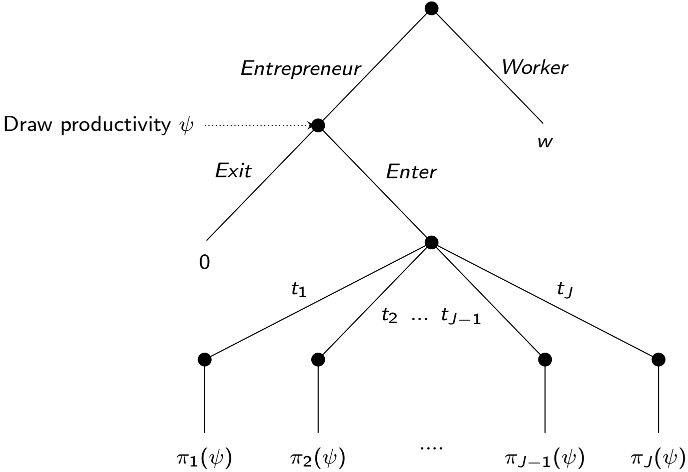
Summary of findings

- **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 $\implies$ firm sizes
   - Prediction 2: scale bias $\implies$ inequality
   - Prediction 3: scale bias $\implies$ profit concentration $\implies$ inequality

Theory: the model visualized



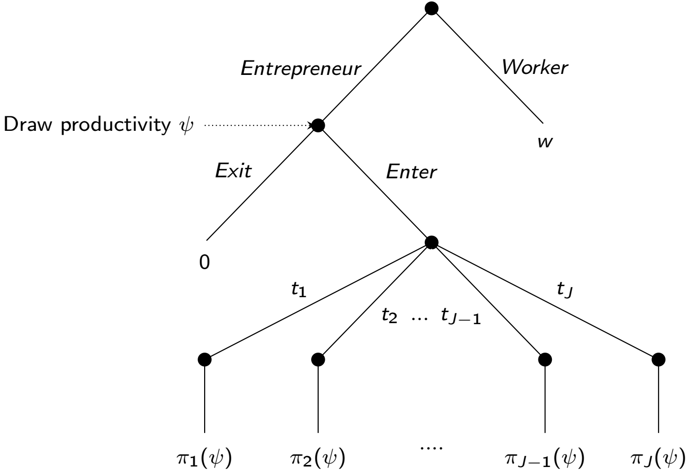
Stage 1: **Occupational choice**

Stage 2: Entry decision

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

Stage 4: Profit maximization

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 $T = \{t_1, .., t_J\}$?

Theory: scale-biased technical change and inequality

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

Theory: scale-biased technical change and inequality

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

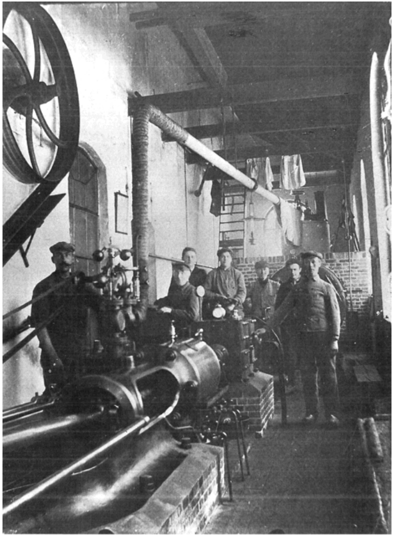
- **Definition:** technical change is large-scale-biased (small-scale-biased) iff it increases (decreases) the average fixed costs in the economy

- **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 $\Longrightarrow$ firm sizes
   - Prediction 2: scale bias $\Longrightarrow$ inequality
   - Prediction 3: scale bias $\Longrightarrow$ profit concentration $\Longrightarrow$ inequality

Comparing two technologies: steam engines and electric motors



Comparing two technologies: the fundamentals

Features	Steam engines	Electric motors
Fixed cost (50 hp, in unskilled wages)	3-4	0.02-0.04
Efficiency increases with size	Strongly	Barely
Source of power	Generated in plant	Purchased
Average capacity (US 1909, in hp)	93.4	8.5
	Large-scale-biased	Small-scale-biased

Sources: own computation based on (Emery, 1883) (for steam engines) and (Bolton, 1926) (for electric motors).

▸ Timing of adoption ▸ Average cost curve ▸ Marginal cost curve ▸ Adoption rates by size

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

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 $\Longrightarrow$ firm sizes
   - Prediction 2: scale bias $\Longrightarrow$ inequality
   - Prediction 3: scale bias $\Longrightarrow$ profit concentration $\Longrightarrow$ inequality

Prediction 1: scale bias $\implies$ 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 $\times$ industry $\times$ year observations
- **Method:** Instrumental variable diff-in-diff
  - Coal access $\implies$ steam engines
  - Hydropower potential $\implies$ electric motors
- **Result:** Large scale-biased technical change increases firm sizes ✓

Steam engines: ▸ Strategy: detail ▸ Strategy: specification ▸ Results
Electric motors: ▸ Strategy: detail ▸ Strategy: specification ▸ Results

Prediction 1: scale bias $\implies$ 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 $\times$ industry $\times$ year observations
- **Method:** Instrumental variable diff-in-diff
  - Coal access $\implies$ steam engines
  - Hydropower potential $\implies$ electric motors
- **Result:** Small scale-biased technical change decreases firm sizes ✓

Steam engines: ▸ Strategy: detail ▸ Strategy: specification ▸ Results
Electric motors: ▸ Strategy: detail ▸ Strategy: specification ▸ Results

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

Prediction 2: scale bias $\implies$ 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 ▸ Source data
  - 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

- **New data:** micro-level data on wealth-at-death from the Netherlands (1879-1927)
  - Digitized around 130,000 images with handwritten text recognition software ▸ Source data
  - 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:** Small scale-biased technical change marginally decreases inequality ✓

Steam engines: ▸ Results OLS ▸ Results IV

Electric motors: ▸ Results OLS ▸ Results IV

Outline

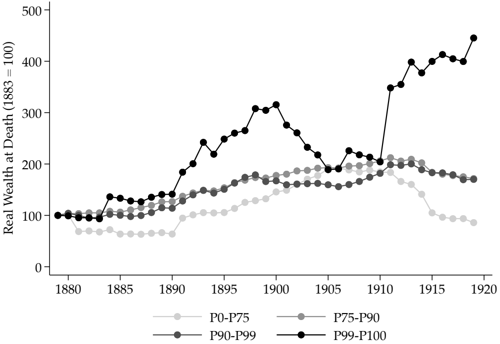
1. Theory: scale-biased technical change and inequality
2. Scale bias in steam engines and electric motors
3. Empirics: testing the theory of scale-biased technical change
   - Prediction 1: scale bias $\implies$ firm sizes
   - Prediction 2: scale bias $\implies$ inequality
   - Prediction 3: scale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

Prediction 3: scale bias $\implies$ profit concentration $\implies$ inequality

- **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?

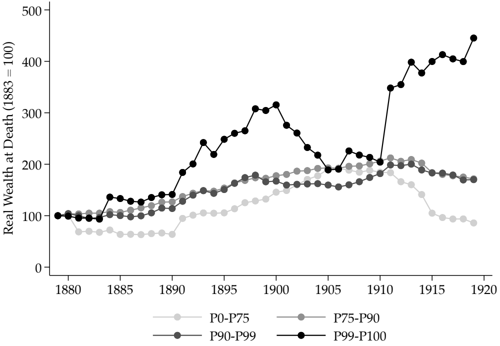
Results: inequality through scale bias, not skill bias

Including textile owners

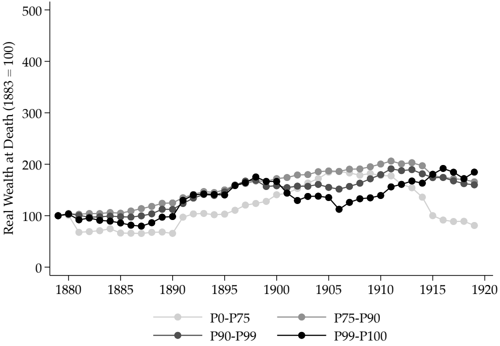


Results: inequality through scale bias, not skill bias

Including textile owners



Excluding textile owners



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

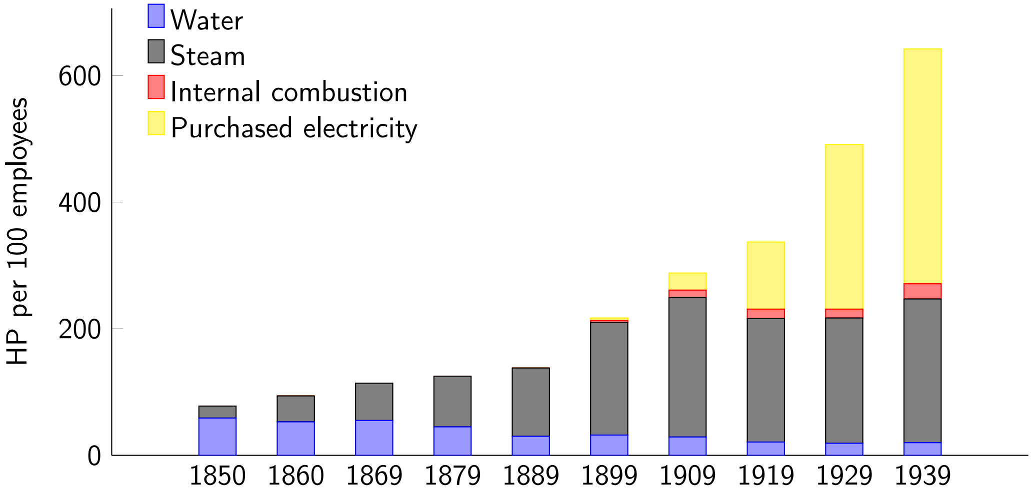
- Effect of technical change on inequality depends on its **scale bias**
  - large-scale-biased technical change: larger firms and more inequality
  - but opposite technologies also exist!
- Large-scale-biased technical change consistent with recent trends
  - decline in entrepreneurship rates (Salgado, '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)
  - 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)
- Provides a framework to think about effects of ongoing technology adoption

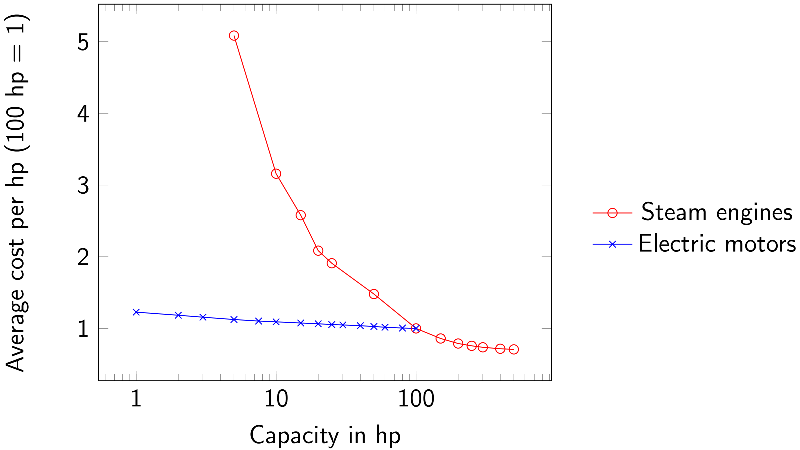
Thank you!

Comparing two technologies: timing of adoption in the United States



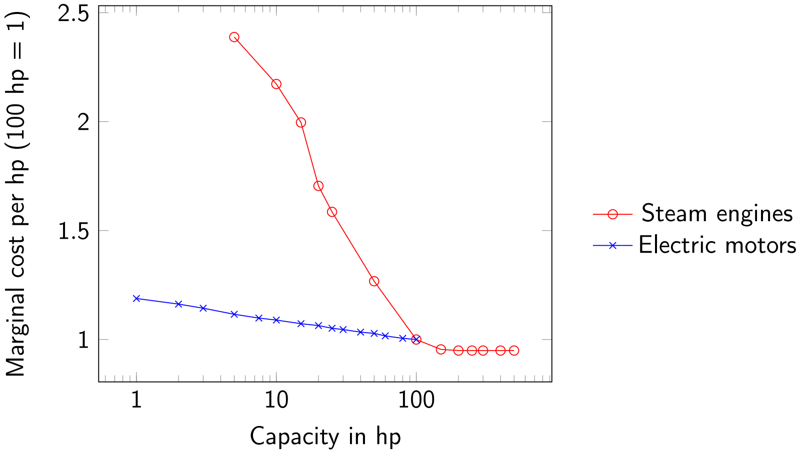
Back

Comparing two technologies: average cost by capacity



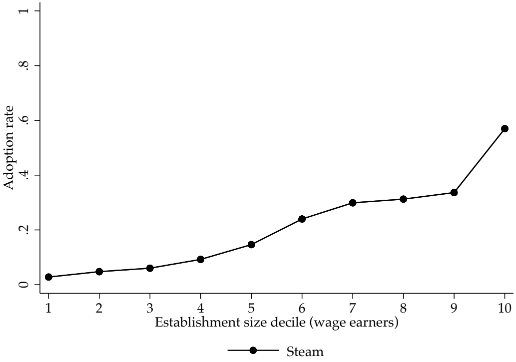
Sources: own computation based on (Emery, 1883) (for steam engines) and (Bolton, 1926) (for electric motors). ▸ Back

Comparing two technologies: marginal cost by capacity

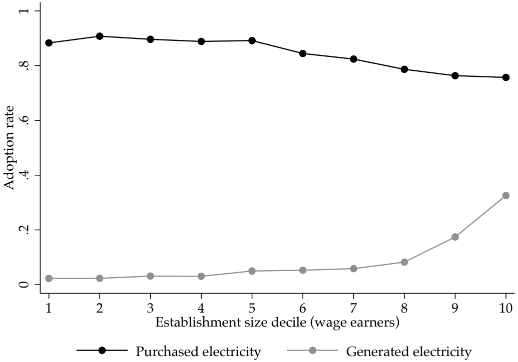


Sources: Own computation based on (Emery, 1883) (for steam engines) and (Bolton, 1926) (for electric motors). ▸ Back

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. ▸ Back

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

▸ Definition of coal access ▸ Map of coal access ▸ Price elasticity ▸ First stage ▸ Back

Strategy: reduced form effect of coal access on firm size

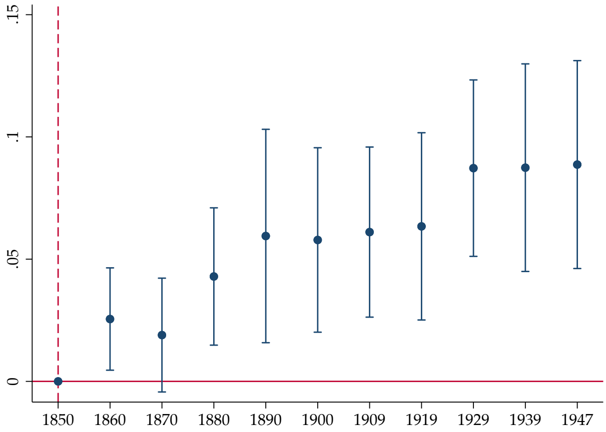
$$\ln\left(y_{ist}\right) = \alpha_s + \eta_{it} + \sum_{t \in T} \beta_t \ln\left(\text{COAL}_s\right) \times \mathbb{1}[\text{Year} = t] + \boldsymbol{\lambda}' \boldsymbol{X}_{ist} + \varepsilon_{ist}$$

where

- i, s, t index industry, state, and year, respectively
- y_{ist} is the average firm size in wage earners
- COAL_s denotes access to coal in state s
- vector of controls $\boldsymbol{X}_{ist}$ contains:
  - density of the population in state s at time t
  - interactions between t and hydropower potential and "market access" in state s

Back

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.

▸ Placebo vs. adopting industries ▸ Back

Strategy: effect of electric motors on firm size

- Theory: electric motor adoption $\iff$ 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 $\approx$ 1900

▸ Map of hydropower potential ▸ Price elasticity ▸ First stage ▸ Back

Strategy: reduced form effect of hydropower on firm size

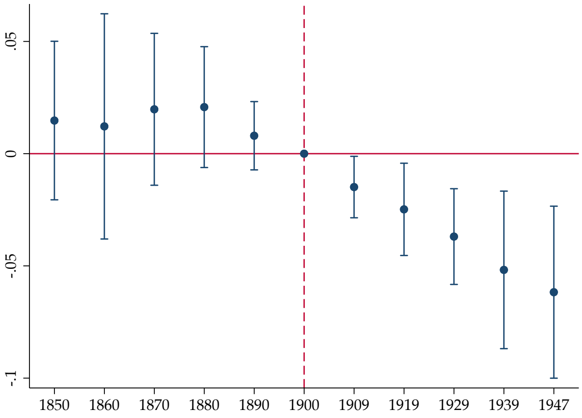
$$\ln(y_{ist}) = \gamma_s + \eta_{it} + \sum_{t \in T} \beta_t \ln(\text{HYDRO}_s) \times \mathbb{1}[\text{Year} = t] + \boldsymbol{\lambda}' \boldsymbol{X}_{ist} + \varepsilon_{ist}$$

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 $\boldsymbol{X}_{ist}$ contains:
  - density of the population in state s at time t
  - interactions between t and coal access and "market access" in state s

Back

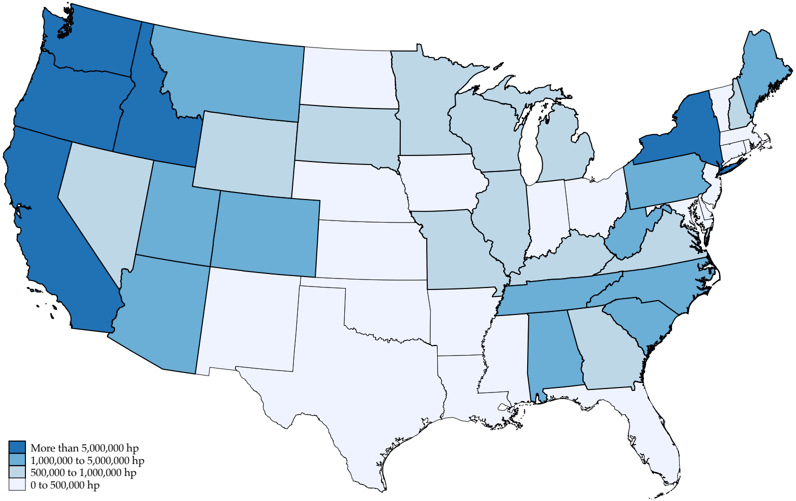
Results: reduced form effect of hydropower on firm size



Standard errors are clustered on the state level. Confidence intervals are at the 95% confidence level.

▸ Placebo vs. adopting industries ▸ Back

Hydropower potential in the US



▸ Back

Definition of coal access

- Analagous to "market access" approach by (Donaldson & Hornbeck, '16)
- Coal access for county c in state s as

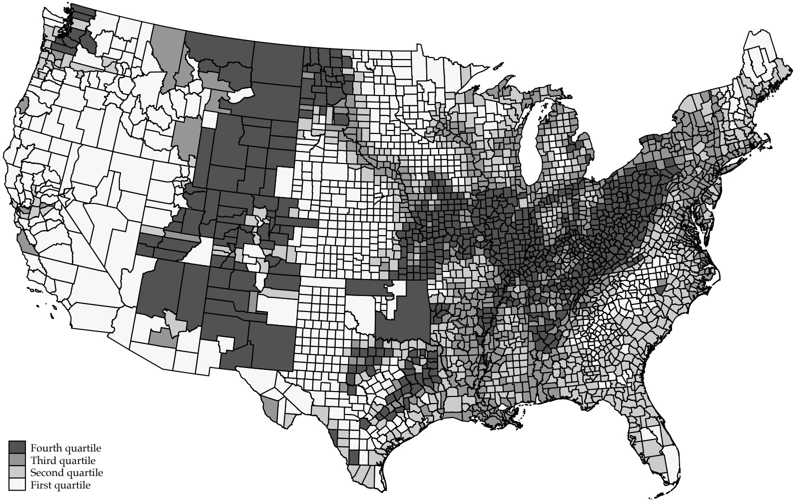
$$\text{COAL}_c^s = \sum_o \tau_{oc}^{-\theta} \text{BTU}_o$$

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

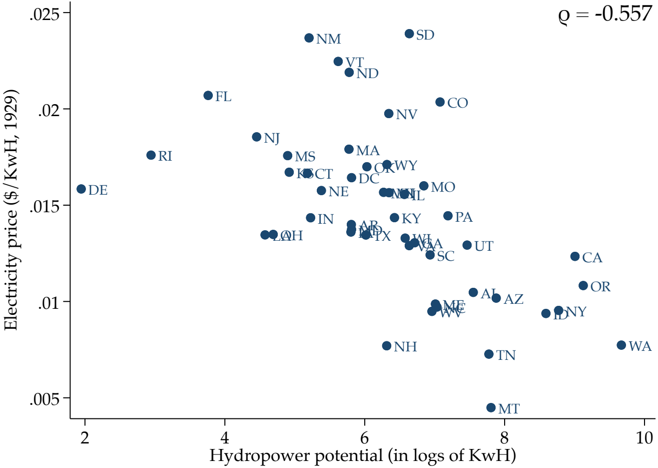
Back

Coal access by US county



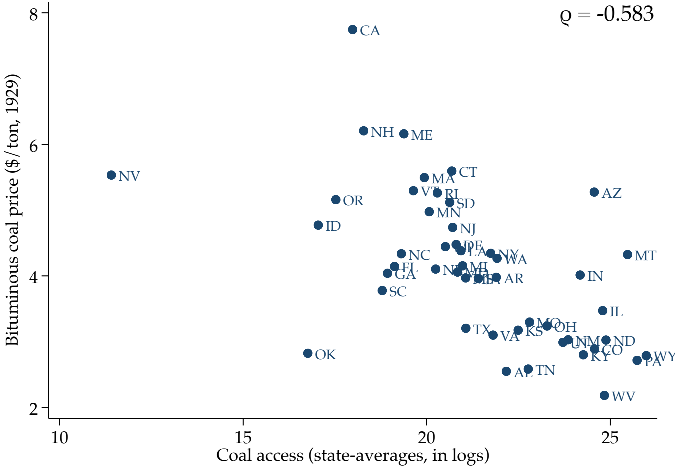
▸ Back

Electricity prices and hydropower potential



▸ Back

Coal prices and resources



▸ Back

First stage: hydropower potential $\Longrightarrow$ purchased electric energy use

	MwH per employee			Electricity as share of fuel costs		
Hydropower potential	0.659***	0.654***	0.646***	0.020***	0.019***	0.017***
	(0.175)	(0.191)	(0.194)	(0.004)	(0.005)	(0.004)
Coal resources		X	X		X	X
Firm size			X			X
Observations	5029	5029	5029	5008	5008	5008

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

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

▸ Back

First stage: coal resources $\implies$ steam engine adoption

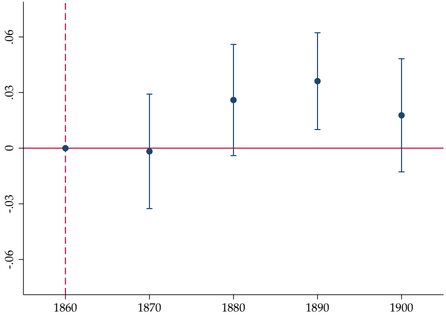
	Steam HP per employee (asinh)			Steam as share of total HP		
Coal access (logs)	0.027***	0.027***	0.026***	0.024***	0.024***	0.023***
	(0.005)	(0.004)	(0.004)	(0.005)	(0.005)	(0.005)
Hydro-potential		X	X		X	X
Firm size			X			X
Observations	3890	3890	3890	3238	3238	3238

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

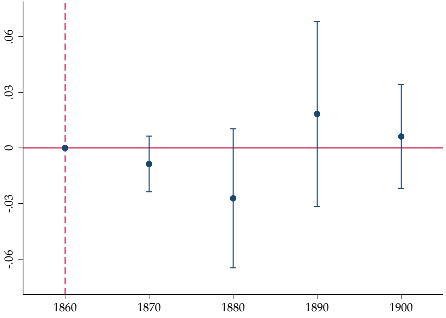
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

▸ Back

Results: heterogeneous effects of coal access



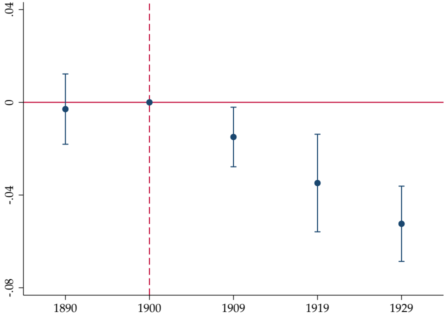
(a) Adopting industries



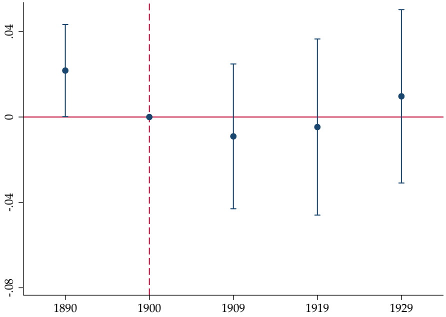
(b) Placebo industries

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. ▸ Back

Results: heterogeneous effects of hydropower potential



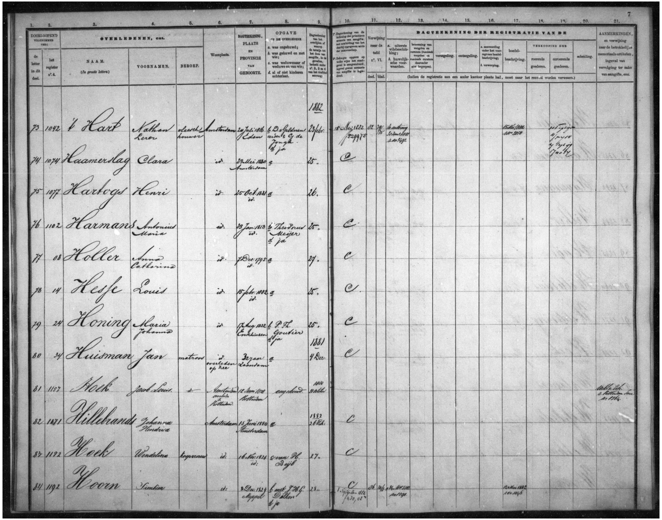
(a) Adopting industries



(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. ▸ Back

Digitized: Micro-level data on wealth (NL, 1879 - 1927)



▸ Back

Strategy: effect of steam engines and electric motors on inequality

–

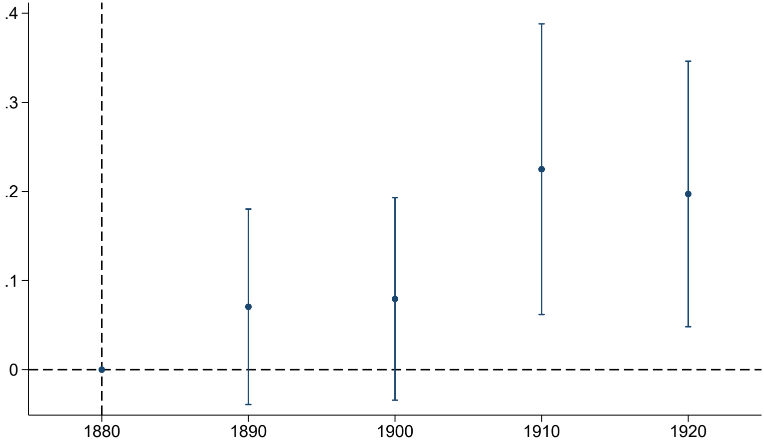
Back

Strategy IV: effect of steam engines on inequality

–

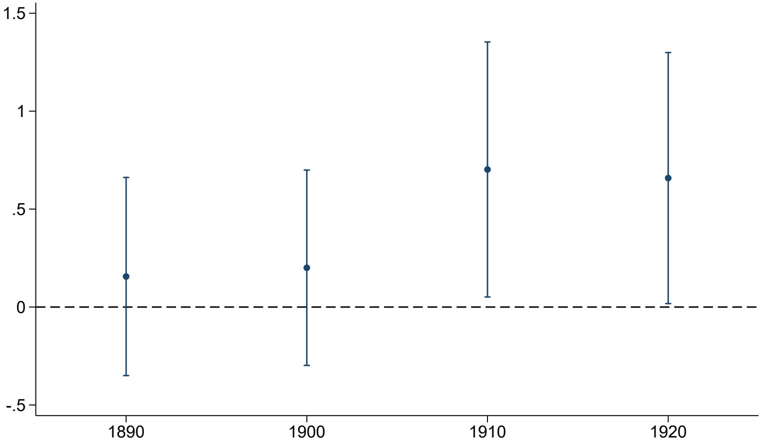
▸ Back

Results: effect of steam engines on inequality



▸ Back

Results IV: effect of steam engines on inequality



Back

Strategy: effect of electric motors on inequality

–

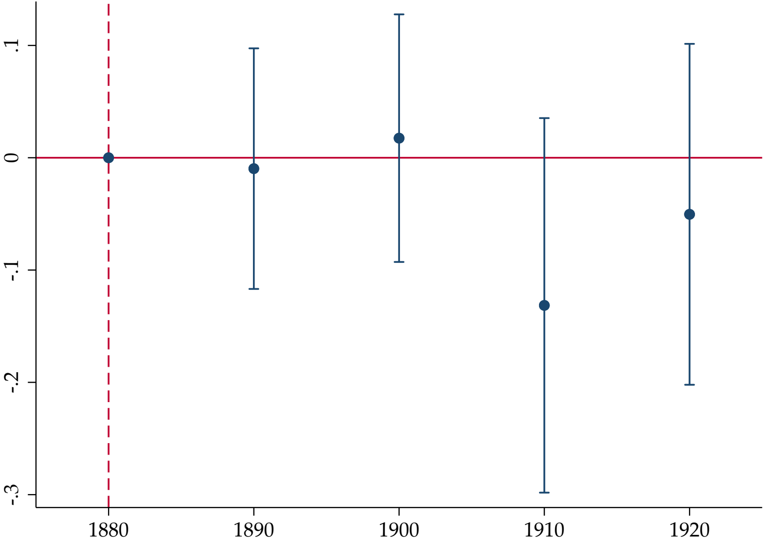
▸ Back

Strategy IV: effect of electric motors on inequality

–

▸ Back

Results: effect of electric motors on inequality



Results IV: effect of electric motors on inequality

Back

Namelist textile merchants Enschede (1795)

ENSCHEDE.

Jan van Lochem
Pieter ter Kuile
De Erven Herman van Lochem
Lazonder en ten Ty en Comp.
De Wed. Jochem Nieuwenhuis
H. en J. Roesſingh
Jan Blydenſtein en Zoon
Engbert ter Kuile
Jan Beukers
Hoedemaker en Comp.
Barend Leurink
Claas ten Cate
Barend Kramer
Arend Coster en Comp.
Maurits Elderink
Lambert Coster
Jan Coster
H. Wennink en Kuite
Hendrikus Pennink
Hendrik ten Cate
Salomon ten Cate
Wed. Antony Hartgerink
Jacob ter Meulen

Deze fabriceeren alle zoorten van gekeperde en ongekeperde Bombazynen, Katoene baaijen, en Marceilles, als mede zommige Els-werkjes en Diemten &c. &c.

Zynde alle deze Fabriekwaaren, byzonder de Bombazyn, veel beter van deugd en qualiteit dan de *Boekholtſche* en *Warendorper* buitenlandſche of Duitſchen,

Jan Rierink en Zoon in Bombazynen in zoorten en Marceilles als voren.

Albert Wallembeck } in Bombazyn.
Willem Reyger }

Hend.

Source: Nieuwe Algemene Konst- en Letterbode (1795, p. 142) ▸ Back