Connecting to Electricity:
Technical Change and Regional Development

Atsuki Kotani
The University of Tokyo

March 8th, 2025

Structural transformation in early 20th-century

- Structural transformation and socio-economic change during electrification.
  - Growth of manufacturing activities (Mumford, 1934, Gordon, 2017, Gaggl et al., 2021).
  - The Second Industrial Revolution.
- Technical change from the steam engine to the electric motor:
  - General purpose technology (Bresnahan and Trajtenberg, 1995).
  - Rapid diffusion and replacement, e.g., $\approx$ 30 years in Japan.
  - $\leftrightarrow$ Many beneficial technologies, e.g., steam engine (Juhász et al., 2024b).
- Seems to be crucial, but we know little about this technical change.
  - What was the driving force?
  - Whether the timing affects the regional development (first-adopter advantage)?

This project: Popularization of powered factory

- Electric motors lower barriers to entry in the mnf. sector with powered factory.
  - Substantial reduction in ***fixed costs*** of technology adoption (Minami, 1979).
  - Small or middle-sized establishments can enter the market w/ powered factory.
  - Growth of manufacturing activities.

- Explore this hypothesis in early 20th-century Japan by combining:
  - **Newly digitized official records** of establishment-level data and electricity access.
  - **Empirical strategy** exploiting geographical suitability of hydropower generation.

- **Key findings**:
  1. Electricity access increased # establishments and manufacturing workers.
  2. New entrants attributed 80% of this manufacturing growth (w.r.t. workers).
  3. Regions with earlier electricity access enjoyed larger economic development, even today.

Related literature

1. Historical impact of electrification:
   - Structural transformation in Norway and the U.S. (Leknes and Modalsli, 2020 Gaggl et al., 2021).
   - *Scale-biased tech change* associates with wealth inequality (Reichardt, 2024).
   - Kitchens and Fishback (2015), Lewis (2018), Lewis and Severnini (2020), Molinder et al. (2021), Kawaguchi et al. (2024).

Related literature

1. Historical impact of electrification:
   - Structural transformation in Norway and the U.S. (Leknes and Modalsli, 2020 Gaggl et al., 2021).
   - *Scale-biased tech change* associates with wealth inequality (Reichardt, 2024).
   - Kitchens and Fishback (2015), Lewis (2018), Lewis and Severnini (2020), Molinder et al. (2021), Kawaguchi et al. (2024).
2. Evolution of the geography of economic activities:
   - Role of history (e.g., Davis and Weinstein, 2002, Bleakley and Lin, 2012, Kline and Moretti, 2014, Hanlon, 2017).
   - Technological shocks: plough (Alesina et al., 2013), printing press (Dittmar, 2011) steam engine (Yamasaki, 2023), tractor (Kitamura, 2022).

Related literature

1. Historical impact of electrification:
   - Structural transformation in Norway and the U.S. (Leknes and Modalsli, 2020 Gaggl et al., 2021).
   - *Scale-biased tech change* associates with wealth inequality (Reichardt, 2024).
   - Kitchens and Fishback (2015), Lewis (2018), Lewis and Severnini (2020), Molinder et al. (2021), Kawaguchi et al. (2024).
2. Evolution of the geography of economic activities:
   - Role of history (e.g., Davis and Weinstein, 2002, Bleakley and Lin, 2012, Kline and Moretti, 2014, Hanlon, 2017).
   - Technological shocks: plough (Alesina et al., 2013), printing press (Dittmar, 2011) steam engine (Yamasaki, 2023), tractor (Kitamura, 2022).
3. Industrialization in Japan:
   - Electric motors favored the growth of small-scale industries (Minami, 1979).
   - Sussman and Yafeh (2000), Bernhofen and Brown (2004), Tang (2014), Morck and Nakamura (2018) Braguinsky et al. (2021), Tang and Basco (2023) Yamasaki (2023), Ichimura et al. (2024), Juhász et al. (2024a).

Related literature

1. Historical impact of electrification:
   - Structural transformation in Norway and the U.S. (Leknes and Modalsli, 2020 Gaggl et al., 2021).
   - *Scale-biased tech change* associates with wealth inequality (Reichardt, 2024).
   - Kitchens and Fishback (2015), Lewis (2018), Lewis and Severnini (2020), Molinder et al. (2021), Kawaguchi et al. (2024).
2. Evolution of the geography of economic activities:
   - Role of history (e.g., Davis and Weinstein, 2002, Bleakley and Lin, 2012, Kline and Moretti, 2014, Hanlon, 2017).
   - Technological shocks: plough (Alesina et al., 2013), printing press (Dittmar, 2011) steam engine (Yamasaki, 2023), tractor (Kitamura, 2022).
3. Industrialization in Japan:
   - Electric motors favored the growth of small-scale industries (Minami, 1979).
   - Sussman and Yafeh (2000), Bernhofen and Brown (2004), Tang (2014), Morck and Nakamura (2018) Braguinsky et al. (2021), Tang and Basco (2023) Yamasaki (2023), Ichimura et al. (2024), Juhász et al. (2024a).

- *In this paper*, ***technical change from steam engines to electric motors***:
  - First empirical evidence that ***new entrants*** drove this tech change and manufacturing growth.
  - The persistent impacts of the timing of electrification.

Outline of Talk

Outline of Talk

Expansion of electricity grids in early 20th Japan

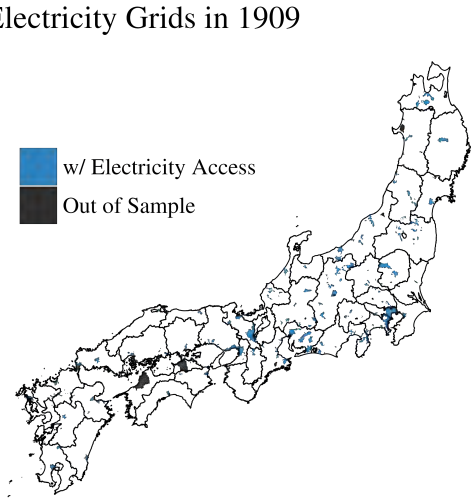
- In the 1880s, electricity supply began in large cities mainly for lighting.
  - Supplied by electric utility companies.
  - Small-scale/high cost of thermal power generation.
  - Modest expansion of electricity supply areas.

- After 1905, the rapid expansion of electricity supply areas due to: (Kurihara, 1964)
  1. Development of long-distance transmission technology.
  2. Low electricity price from hydroelectric power.
  - $\rightarrow$ Dramatic increase in electricity demand from manufacturing sectors.

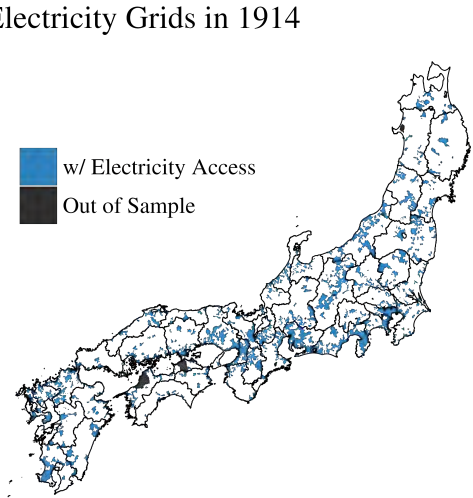
- By 1929, over 95% of municipalities got electricity access.

▸ Power Generation ▸ Power Source Transition

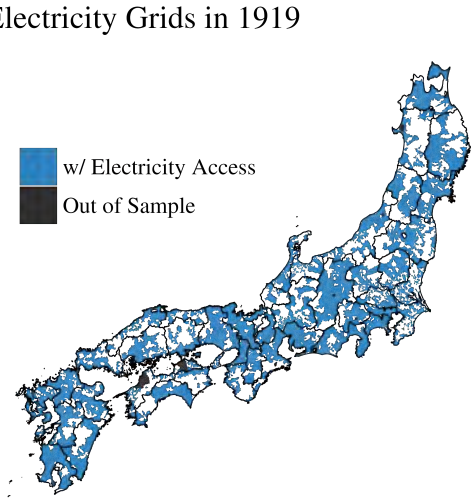
Expansion of electricity grids



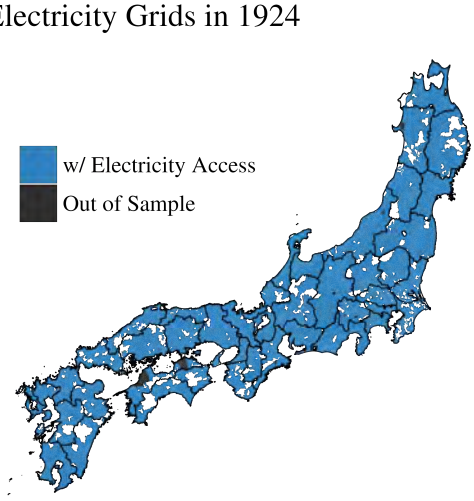
Expansion of electricity grids



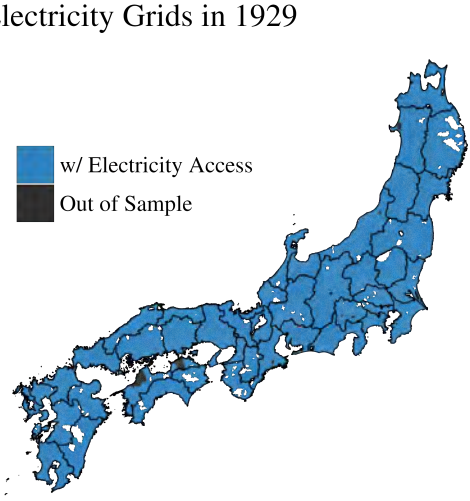
Expansion of electricity grids



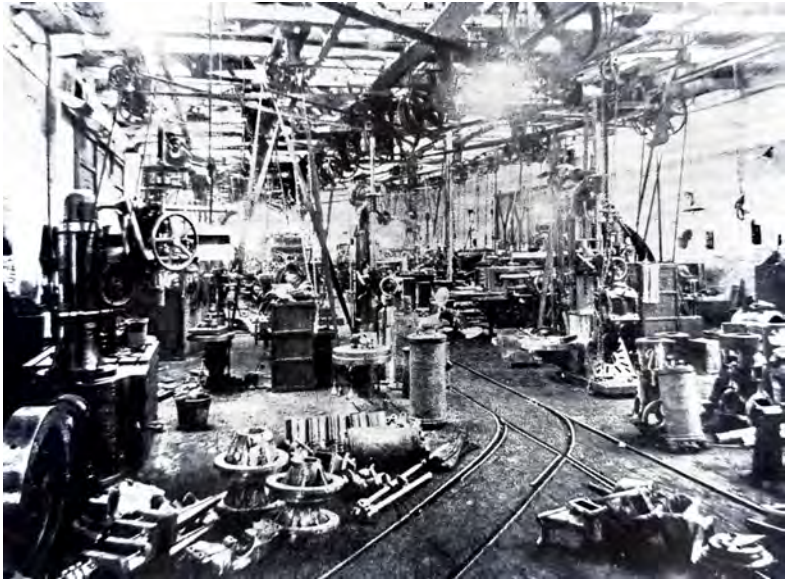
Expansion of electricity grids



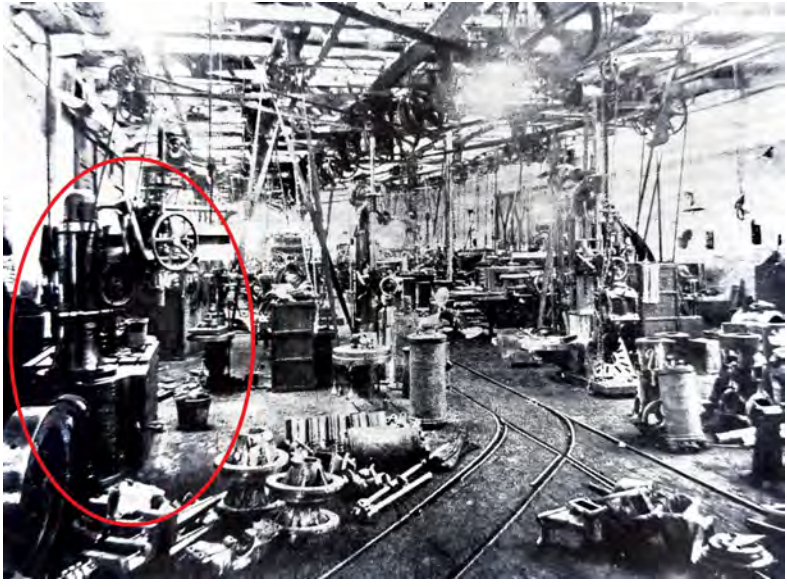
Expansion of electricity grids



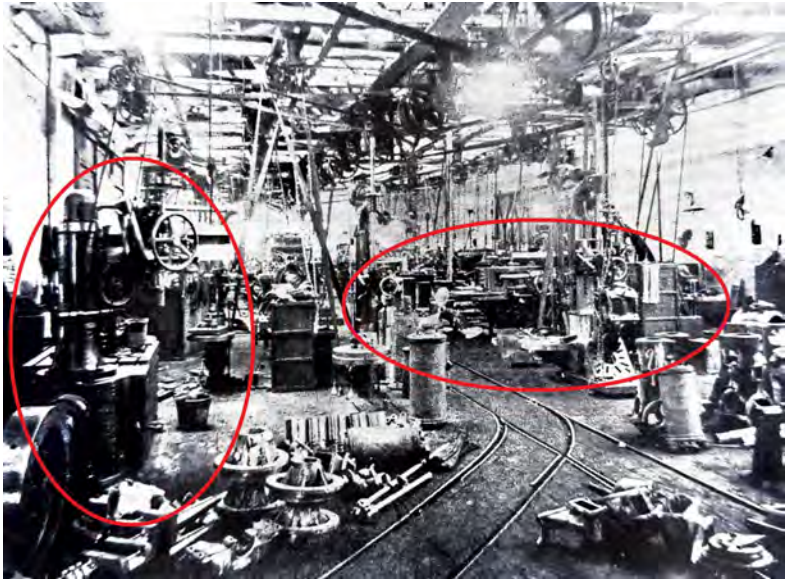
Steam engine entails high fixed cost (*Group drive system*)



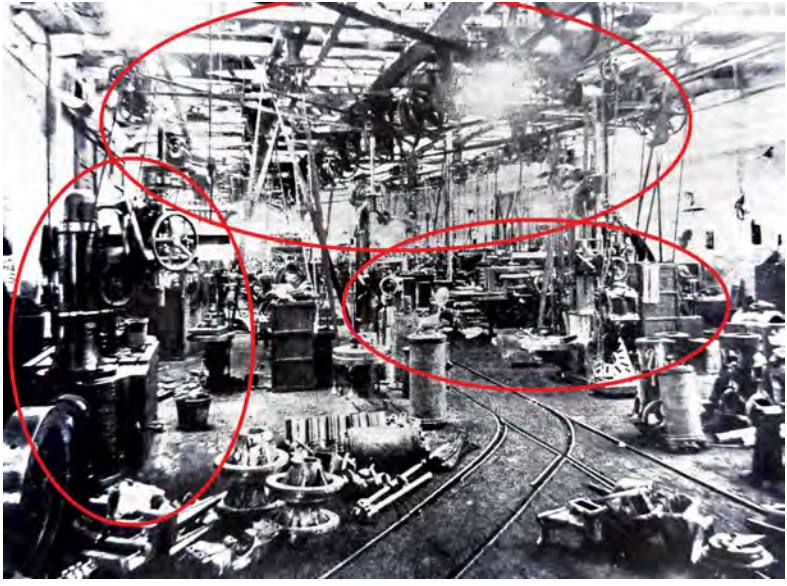
Steam engine entails high fixed cost (*Group drive system*)



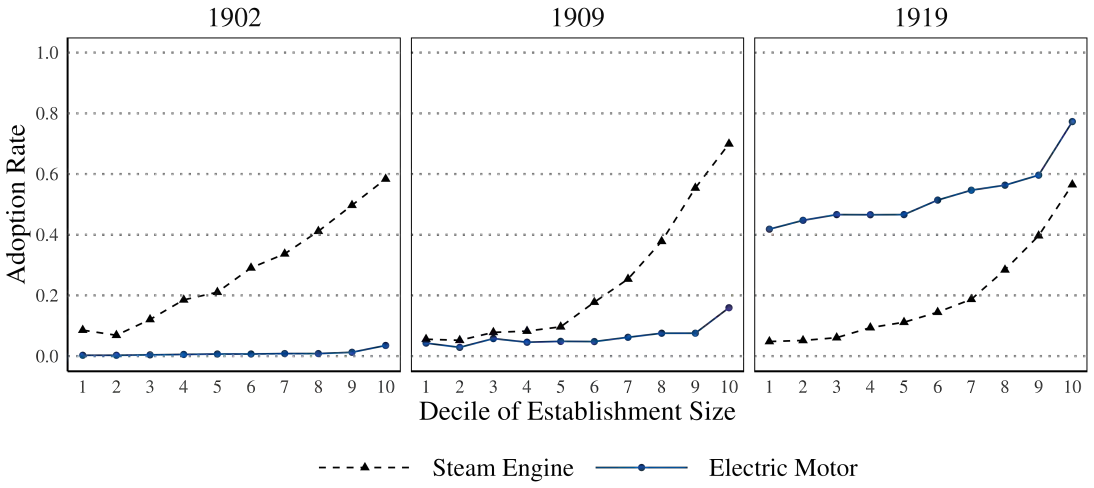
Steam engine entails high fixed cost (*Group drive system*)



Steam engine entails high fixed cost (*Group drive system*)



Popularization of powered factory



▸ Transition by industry ▸ Textile ▸ Machinery ▸ Metal ▸ Food ▸ Chemical ▸ Miscellaneous

Outline

Data: Newly digitized official records

1. **Handbook of Factory** (*Kojo Turan*):
   - All est. with 10+ workers (1902, 1909, 1916, 1919).
   - # male/female workers, # and HP of power source, industry, founded year, and address.
   - # establishments: 11,914 in 1909, 23,004 in 1919.

2. **Handbook of Electric Utility Industry** (*Denki Jigo Yoran*):
   - Published every year and provides the license status of each electric utility company.
   - Digitization every five years after 1909 (municipality-level).
   - Location of the power stations.

3. **Other economic outcomes**:
   - Population census in early 20th-century.
   - Orbis firm database for today's economic activities.

IV: Hydropower potential

- Theoretical hydropower potential of hydropower generation in basin j: (Arai et al., 2022)

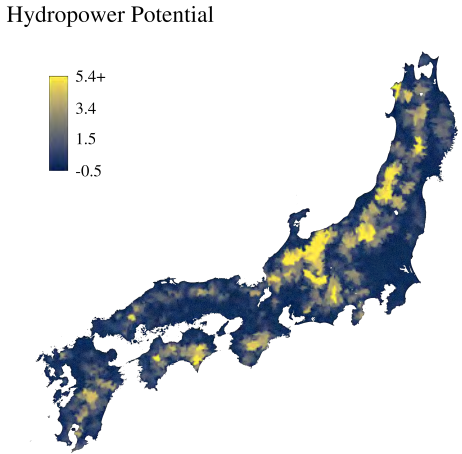
$$\text{Hydropower Potential}_j = \text{Water Volume Index}_j \times \text{Hydraulic Head Height}_j.$$

  - Power generation depends on streamflow and hydraulic head (Basso and Botter, 2012).
  - Water Volume Index$_j$: Cumulative annual flow volume of basin j.
  - Hydraulic Head Height$_j$: Elevation difference between the basin and areas within a 1km.

- Arai et al. (2022) estimates the W_i for small-sized basins ($\approx 10 km^2$) in Japan with
  - 176 basin geographical characteristics.
  - 389 basins with discharge records (ave. 17.1 years).
  - Neural network model.

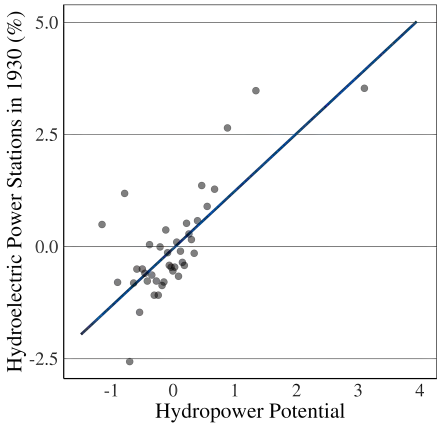
Geographical distribution of hydropower potential

(a) Topography

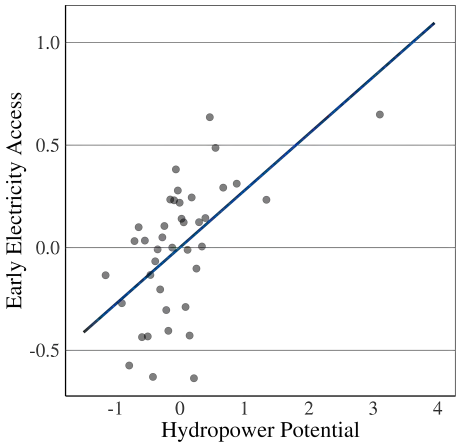


(b) Hydropower potential

Hydropower potential, hydroelectric generation, and early access



(a) Hydroelectric generation



(b) Early electricity access

Hydropower potential and economic activities

$$
\begin{aligned}
\mathrm{Y}_{it} = & \sum_{t \neq 1909} \beta_t \, \text{Hydropower Potential}_i \times \mathbf{1}\{\text{Year} = t\} + \\
& \sum_{t \neq 1909} \lambda_t \, \ln(\text{PopDens}_{i,1908}) \times \mathbf{1}\{\text{Year} = t\} + \\
& \sum_{t \neq 1909} \gamma_t \, \text{Geography}_i \times \mathbf{1}\{\text{Year} = t\} + \alpha_i + \delta_t + v_{it},
\end{aligned}
$$

- i: municipality where electricity supply began after 1909.
- $t \in \{1902, 1909, 1916, 1919\}$: year.
- Y_{it}: # establishments.
- Hydropower potential$_i$: Suitability for hydropower generation.
- Geography$_i$: Area size, dist. to the coast, and dist. metropolis.
- (α_i, δ_t): municipality and year fixed effects.

Hydropower potential matters only after the grid expansion

	Number of Establishments					
	Total			w/ Electric Motor		
	(1)	(2)	(3)	(4)	(5)	(6)
Hydropower Potential × 1902	-0.024	-0.020	-0.004	-0.001	-0.001	-0.001
	(0.022)	(0.023)	(0.023)	(0.001)	(0.001)	(0.001)
Hydropower Potential × 1916	0.015	0.023	0.018	0.047***	0.044***	0.040***
	(0.016)	(0.016)	(0.017)	(0.007)	(0.007)	(0.008)
Hydropower Potential × 1919	0.091**	0.090**	0.080**	0.101***	0.093***	0.081***
	(0.036)	(0.037)	(0.038)	(0.014)	(0.013)	(0.013)
Streamflow × Year FE		✓	✓		✓	✓
Ruggedness × Year FE			✓			✓
Observations	40,020	40,020	40,020	40,020	40,020	40,020
Adjusted R^2	0.68	0.68	0.68	0.34	0.34	0.34
Mean of dep.var	0.72	0.72	0.72	0.13	0.13	0.13

Notes: *, **, and *** indicate significance at the 10%, 5%, and 1% levels. Robust standard errors clustered at the municipality level are reported in parentheses.

Outline

Main Specification

$$\Delta \mathrm{Y}_{ip} = \eta\, \text{Electricity Access}_{i,1914} + \theta\, \ln(\text{PopDens}_{i,1908}) + \pi\, \text{Geography}_i + \tau_p + \varepsilon_{ip},$$

- i: municipality w/o electricity supply in 1909, p: prefecture.
- ΔY_{ip}: Change in outcomes from 1909 to 1919.
- $\text{Electricity Access}_{i,1914}$: Electricity accessibility in municipality i in 1914
- $\ln(\text{PopDens}_{i,1908})$: Log of population density in 1908.
- Geography_i: Area size, dist. to the coast, and dist. metropolis.
- τ_p: prefecture fixed effects.

▸ 1st stage

2nd stage: Effect of electricity access on industrialization

	Δ Number of Establishments (1909-1919)				Demographics	
	Total (1)	w/ Electric Motor (2)	Total (3)	w/ Electric Motor (4)	Δ Mnf. Workers (1909-1919) (5)	Δ Pop. (1908-1918) (6)
Electricity Access in 1914	0.307***	0.559***	2.00**	1.29***	121.7***	165.6
	(0.090)	(0.064)	(1.02)	(0.404)	(43.3)	(371.8)
Model	OLS	OLS	IV	IV	IV	IV
Prefecture FE	✓	✓	✓	✓	✓	✓
Geography	✓	✓	✓	✓	✓	✓
Pop. density 1908	✓	✓	✓	✓	✓	✓
Streamflow	✓	✓	✓	✓	✓	✓
Ruggedness	✓	✓	✓	✓	✓	✓
Observations	10,005	10,005	10,005	10,005	10,005	9,991
First stage F-stat			65.9	65.9	65.9	66.7
Mean of dep.var	0.30	0.36	0.30	0.36	24.7	228.1

Notes: Robust standard errors clustered by municipalities within 30km radius, following Conley (1999), are reported in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels.

Main result: Robustness

- **Placebo test** ‣ Placebo
  - Concern about unobserved preexisting regional characteristics.
  - Replacing the outcome with the change in 1902-1909 (= before the access).
  - $\rightarrow$ Much smaller and insignificant effect.

- **Railway access** ‣ Railway
  - Railway access may induce technology adoption through market access (Yamasaki, 2023).
  - Including Δ in the dist. to the railway station as a control.
  - $\rightarrow$ Nearly identical and still statistically significant.

- **Infrastructure investment** ‣ Infrastructure
  - Infrastructure investment (e.g., dams) may spur manufacturing (Kline and Moretti, 2014).
  - Excluding the municipalities with large hydropower stations in 1930.
  - $\rightarrow$ Slightly smaller but still statistically significant.

Entrants drove manufacturing growth

	Number of Establishments						Demographics	
	Total		w/ Steam Engine		w/ Electric Motor		Mnf. Workers	
	(1) Δ All	(2) Entrant	(3) Δ All	(4) Entrant	(5) Δ All	(6) Entrant	(7) Δ All	(8) Entrant
Electricity Access in 1914	2.00**	2.69***	0.277	0.273	1.29***	0.909***	121.7***	105.3***
	(1.02)	(0.858)	(0.215)	(0.170)	(0.404)	(0.265)	(43.3)	(37.5)
Model	IV	IV	IV	IV	IV	IV	IV	IV
Prefecture FE	✓	✓	✓	✓	✓	✓	✓	✓
Geography	✓	✓	✓	✓	✓	✓	✓	✓
Pop. density 1908	✓	✓	✓	✓	✓	✓	✓	✓
Streamflow	✓	✓	✓	✓	✓	✓	✓	✓
Ruggedness	✓	✓	✓	✓	✓	✓	✓	✓
Observations	10,005	10,005	10,005	10,005	10,005	10,005	10,005	10,005
First stage F-stat	65.9	65.9	65.9	65.9	65.9	65.9	65.9	65.9
Mean of dep.var	0.30	0.58	0.05	0.14	0.36	0.23	24.7	28.3

Notes: Robust standard errors clustered by municipalities within 30km radius, following Conley (1999), are reported in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels.

Outline

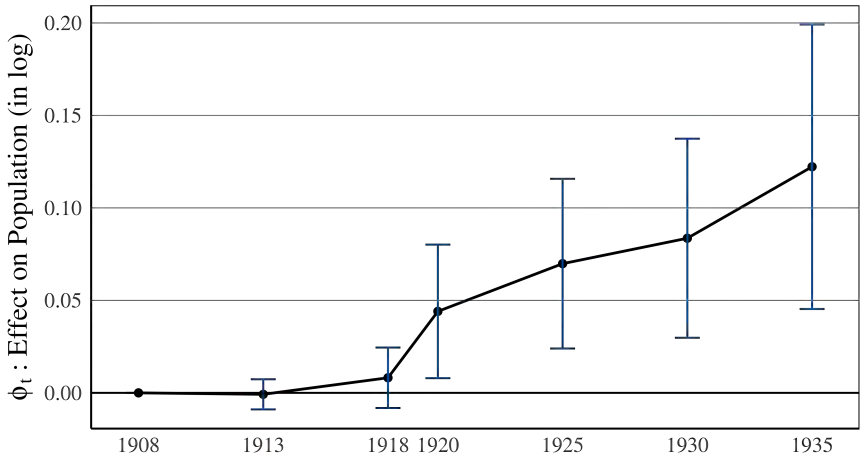
Population growth after electrification

2nd stage:

$$\ln\left(\frac{\text{Population}_{it}}{\text{Population}_{i,1908}}\right) = \phi_t \text{Early Electricity Access}_i + \kappa_t \ln(\text{PopDens}_{i,1908}) + \xi_t \text{Geography}_i + \varsigma_{pt} + \epsilon_{ipt},$$

- i: municipality w/o electricity supply in 1909, p: prefecture, t: year.
- Population_{it}: Population in municipality i in year t.
- $\text{Early Electricity Access}_i$: 1929 minus the year of first electricity access
- $\ln(\text{PopDens}_{i,1908})$: Log of population density in 1908.
- Geography_i: Area size, dist. to the coast, and dist. metropolis.
- ς_{pt}: prefecture-year fixed effects.

First-adopter advantage



Notes: Robust standard errors are clustered by municipalities within 30km radius, following Conley (1999). Confidential intervals are calculated at the 95% level. Note that number of observations is 9,950 and the first stage F-statistic is 22.2.

Long-run effect: Economic activities today

	Num. of Firms		Num. of Emp.		Ave. Sales		Sales/Emp.	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Early Electricity Access	0.057***	0.158*	0.066***	0.185*	0.024***	0.095*	0.010***	0.067*
	(0.004)	(0.084)	(0.005)	(0.103)	(0.003)	(0.054)	(0.002)	(0.039)
Model	OLS	IV	OLS	IV	OLS	IV	OLS	IV
Prefecture FE	✓	✓	✓	✓	✓	✓	✓	✓
Geography	✓	✓	✓	✓	✓	✓	✓	✓
Pop. density 1908	✓	✓	✓	✓	✓	✓	✓	✓
Streamflow	✓	✓	✓	✓	✓	✓	✓	✓
Ruggedness	✓	✓	✓	✓	✓	✓	✓	✓
Observations	9,852	9,852	9,474	9,474	9,852	9,852	9,474	9,474
First stage F-stat		26.4		29.6		26.4		29.6
Mean of dep.var	3.4	3.4	5.0	5.0	7.8	7.8	6.3	6.3

Notes: Robust standard errors clustered by municipalities within 30km radius, following Conley (1999), are reported in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels.

Conclusion

- Summary of this project:
  - Electricity access stimulated manufacturing activities, in particular w/ electric motors.
  - This manufacturing growth was driven by new entrants.
  - In addition, regions w/ earlier access enjoyed higher population growth.
  - Today, these regions have more firms, higher sales, and more employees.

- Future works:
  - Productivity changes depending on the establishment size.
  - Detailed mechanisms behind the persistent effects.
  - (e.g., agglomeration of small-scale industry).

Reference I

Alesina, Alberto, Paola Giuliano, and Nathan Nunn. 2013. "On the Origins of Gender Roles: Women and the Plough." *The Quarterly Journal of Economics* 128 (2): 469–530.

Arai, Ryosuke, Yasushi Toyoda, and So Kazama. 2022. "Streamflow Maps for Run-of-River Hydropower Developments in Japan." *Journal of Hydrology* 607 127512.

Basso, S, and G Botter. 2012. "Streamflow Variability and Optimal Capacity of Run-of-river Hydropower Plants." *Water Resources Research* 48 (10): .

Bernhofen, Daniel M, and John C Brown. 2004. "A Direct Test of the Theory of Comparative Advantage: The Case of Japan." *Journal of Political Economy* 112 (1): 48–67.

Bleakley, Hoyt, and Jeffrey Lin. 2012. "Portage and Path Dependence." *The Quarterly Journal of Economics* 127 (2): 587–644.

Braguinsky, Serguey, Atsushi Ohyama, Tetsuji Okazaki, and Chad Syverson. 2021. "Product Innovation, Product Diversification, and Firm Growth: Evidence from Japan's Early Industrialization." *American Economic Review* 111 (12): 3795–3826.

Bresnahan, Timothy F, and M Trajtenberg. 1995. "General Purpose Technologies 'Engines of Growth'?" *Journal of Econometrics* 65 (1): 83–108.

Conley, T G. 1999. "GMM Estimation with Cross Sectional Dependence." *Journal of Econometrics* 92 (1): 1–45.

Davis, Donald R, and David E Weinstein. 2002. "Bones, Bombs, and Break Points: The Geography of Economic Activity." *American Economic Review* 92 (5): 1269–1289.

Reference II

Dittmar, Jeremiah E. 2011. "Information Technology and Economic Change: The Impact of the Printing Press." *The Quarterly Journal of Economics* 126 (3): 1133–1172.

Gaggl, Paul, Rowena Gray, Ioana Marinescu, and Miguel Morin. 2021. "Does Electricity Drive Structural Transformation? Evidence from the United States." *Labour Economics* 68 101944.

Gordon, Robert. 2017. *The Rise and Fall of American Growth: The U.S. Standard of Living Since the Civil War*. Princeton: Princeton University Press.

Hanlon, W Walker. 2017. "Temporary Shocks and Persistent Effects in Urban Economies: Evidence from British Cities after the U.S. Civil War." *The Review of Economics and Statistics* 99 (1): 67–79.

Ichimura, Hidehiko, Yasuyuki Sawada, Yutaro Takayasu, and Mari Tanaka. 2024. "A Rise of New Elites? The Role of Secondary Schools in Early Development." *mimeo*.

Juhász, Réka, Shogo Sakabe, and David Weinstein. 2024a. "Codification, Technology Absorption, and the Globalization of the Industrial Revolution." *NBER Working Paper Series*.

Juhász, Réka, Mara P Squicciarini, and Nico Voigtländer. 2024b. "Technology Adoption and Productivity Growth: Evidence from Industrialization in France." *Journal of Political Economy* 000–000.

Kawaguchi, Daiji, Tetsuji Okazaki, and Xuanli Zhu. 2024. "Factory Automation, Labor Demand, and Local Labor Market." *IZA Discussion Paper Series*.

Kitamura, Shuhei. 2022. "Tillers of Prosperity: Land Ownership, Reallocation, and Structural Transformation." *OSF Preprints*.

Reference III

Kitchens, Carl, and Price Fishback. 2015. "Flip the Switch: The Impact of the Rural Electrification Administration 1935-1940." *Journal of Economic History* 75 (4): 1161–1195.

Kline, Patrick, and Enrico Moretti. 2014. "Local Economic Development, Agglomeration Economies, and the Big Push: 100 Years of Evidence from the Tennessee Valley Authority." *The Quarterly Journal of Economics* 129 (1): 275–331.

Kurihara, Toyo. 1964. *Denryoku (Electric Utility)*. Tokyo: Kojunsha.

Leknes, Stefan, and Jørgen Modalsli. 2020. "Who Benefited from Industrialization? The Local Effects of Hydropower Technology Adoption in Norway." *Journal of Economic History* 80 (1): 207–245.

Lewis, Joshua. 2018. "Infant Health, Women's Fertility, and Rural Electrification in the United States, 1930–1960." *Journal of Economic History* 78 (1): 118–154.

Lewis, Joshua, and Edson Severnini. 2020. "Short- and Long-run Impacts of Rural Electrification: Evidence from the Historical Rollout of the U.S. Power Grid." *Journal of Development Economics* 143 102412.

Minami, Ryoshin. 1979. *Doryoku Kakumei to Gijutsu Simpo - Senzen Seizoki no Bunseki (Power Source Revolution and Technological Progress)*. Tokyo: Sanseido.

Molinder, Jakob, Tobias Karlsson, and Kerstin Enflo. 2021. "More Power to the People: Electricity Adoption, Technological Change, and Labor Conflict." *Journal of Economic History* 81 (2): 481–512.

Morck, Randall, and Masao Nakamura. 2018. "Japan's Ultimately Unaccursed Natural Resources-Financed Industrialization." *Journal of the Japanese and International Economies* 47 32–54.

Mumford, Lewis. 1934. *Technics and Civilization*. London: Routledge.

Reichardt, Hugo. 2024. "Scale-Biased Technical Change and Inequality." *mimeo*.

Reference IV

Sussman, Nathan, and Yishay Yafeh. 2000. "Institutions, Reforms, and Country Risk: Lessons from Japanese Government Debt in the Meiji Era." *Journal of Economic History* 60 (2): .

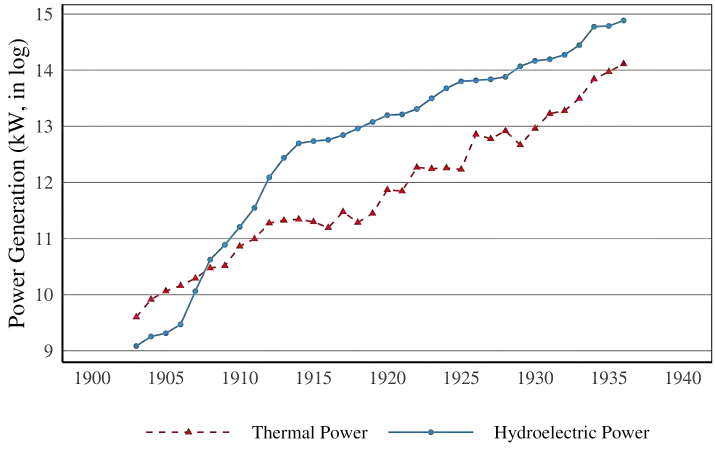
Tang, John P. 2014. "Railroad Expansion and Industrialization: Evidence from Meiji Japan." *Journal of Economic History* 74 (3): 863–886.

Tang, John P, and Sergi Basco. 2023. "Banks, Credit Supply, and the Life Cycle of Firms: Evidence from Late Nineteenth Century Japan." *Journal of Banking and Finance* 154 (106937): 106937.

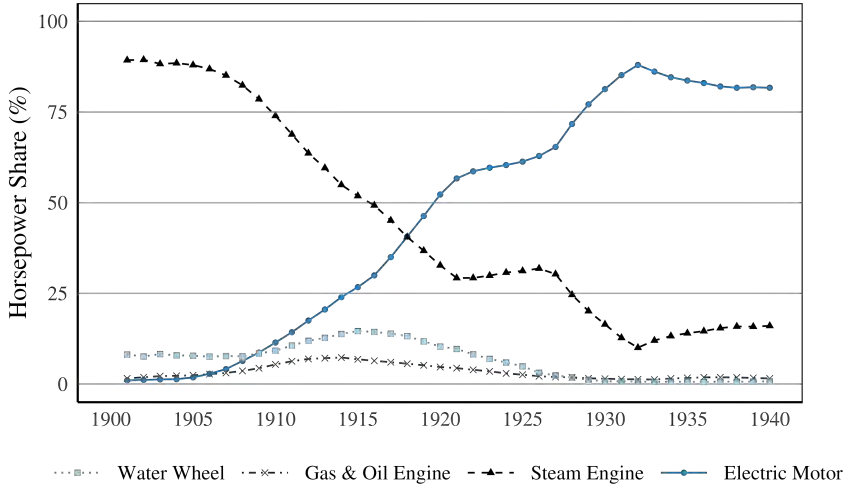
Yamasaki, Junichi. 2023. "Railroads, Technology Adoption, and Modern Economic Development: Evidence from Japan." *SSRN Electronic Journal*.

Source of power generation

Figure: Source of Power Generation

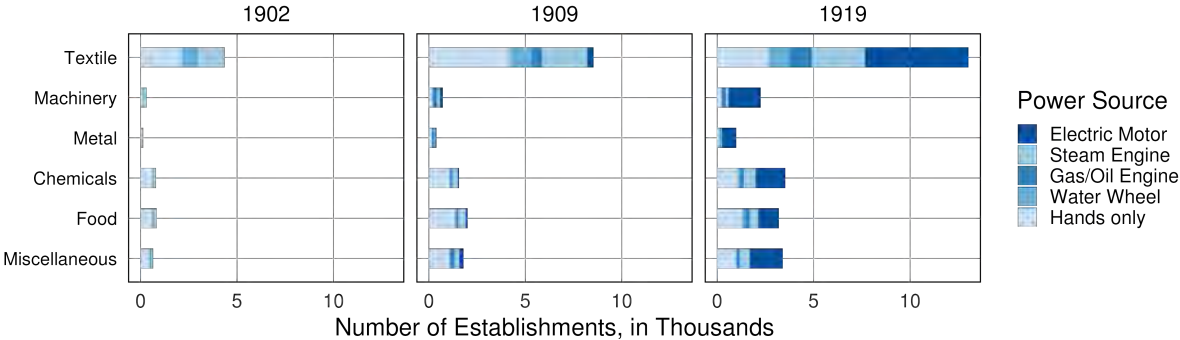


Transition of power source



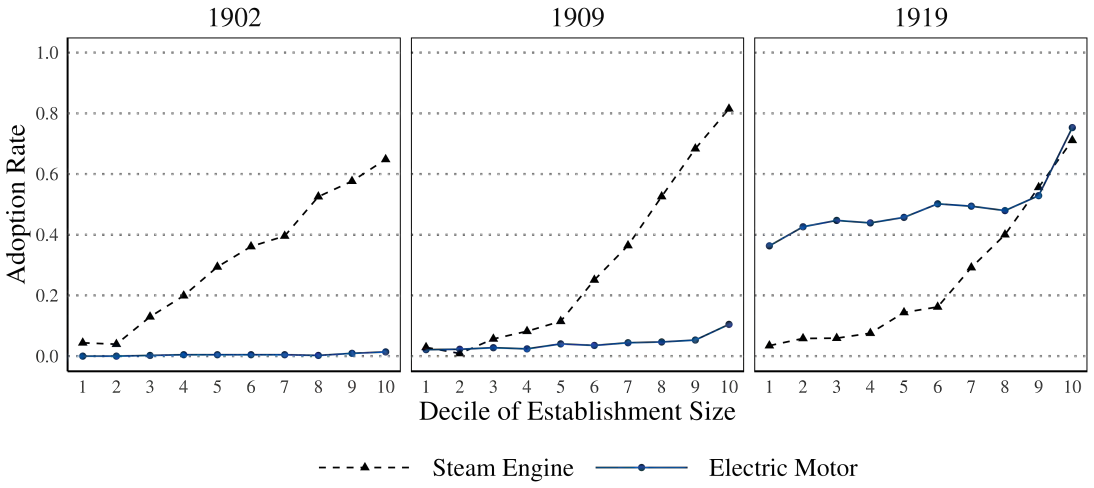
Back

Power source transitoin by industry



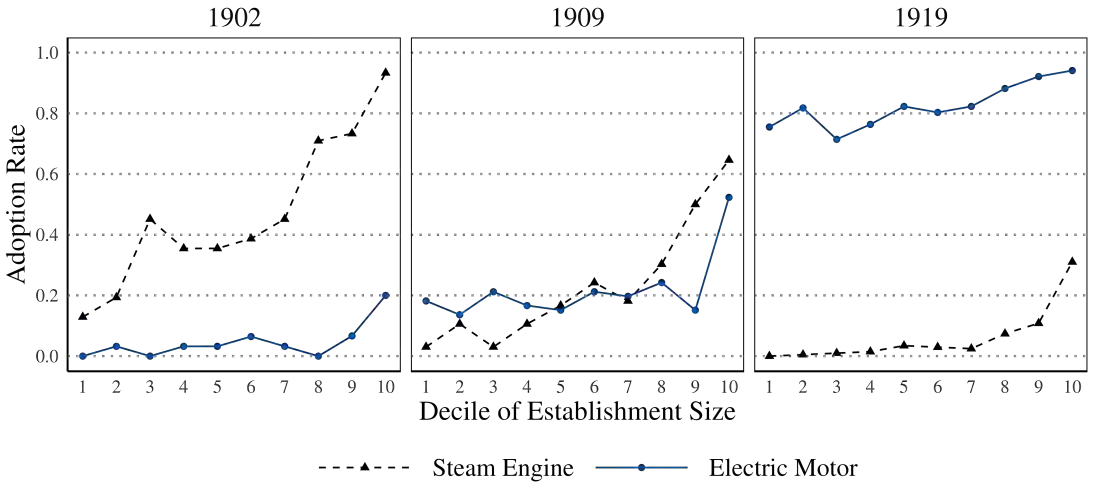
Back

Popularization of powered factory (Textile)



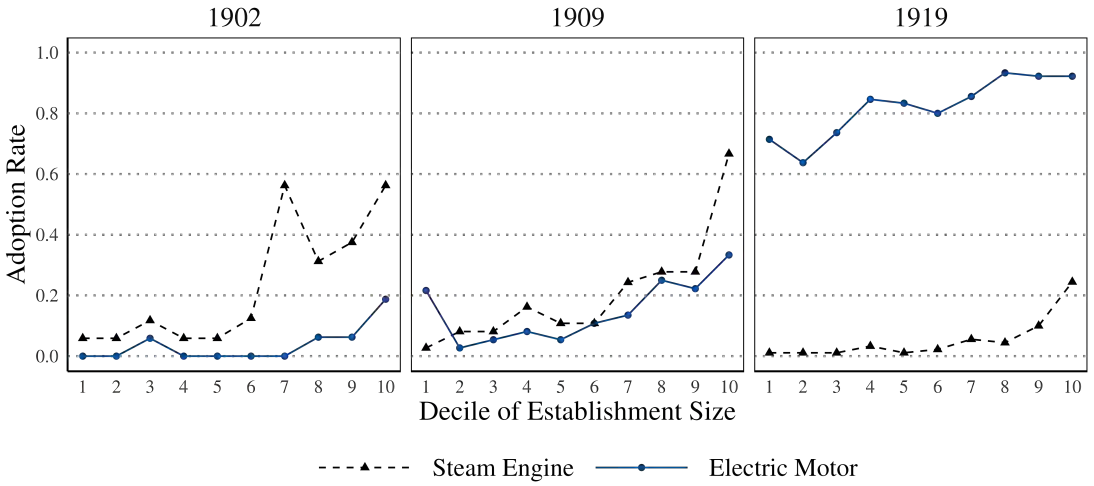
Back

Popularization of powered factory (Machinery)



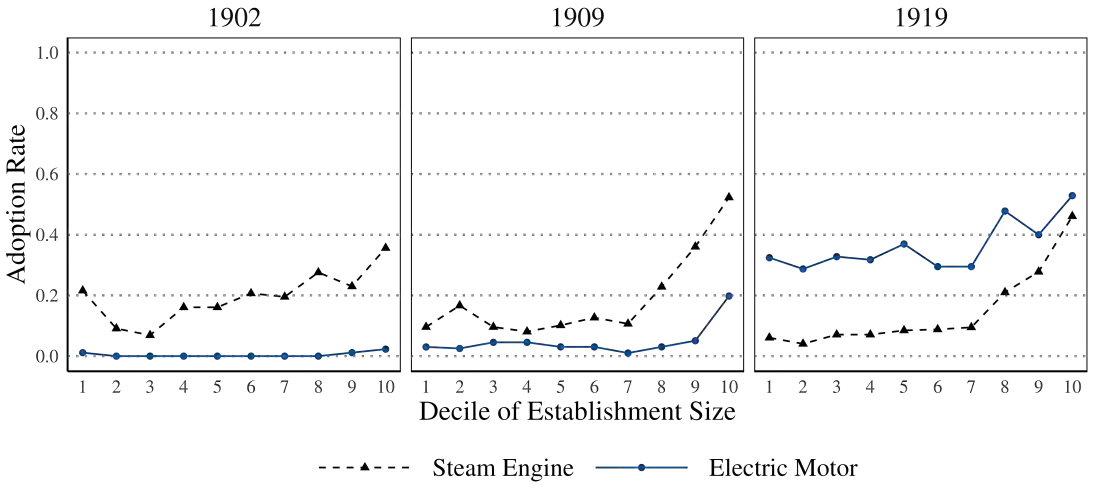
Back

Popularization of powered factory (Metal)



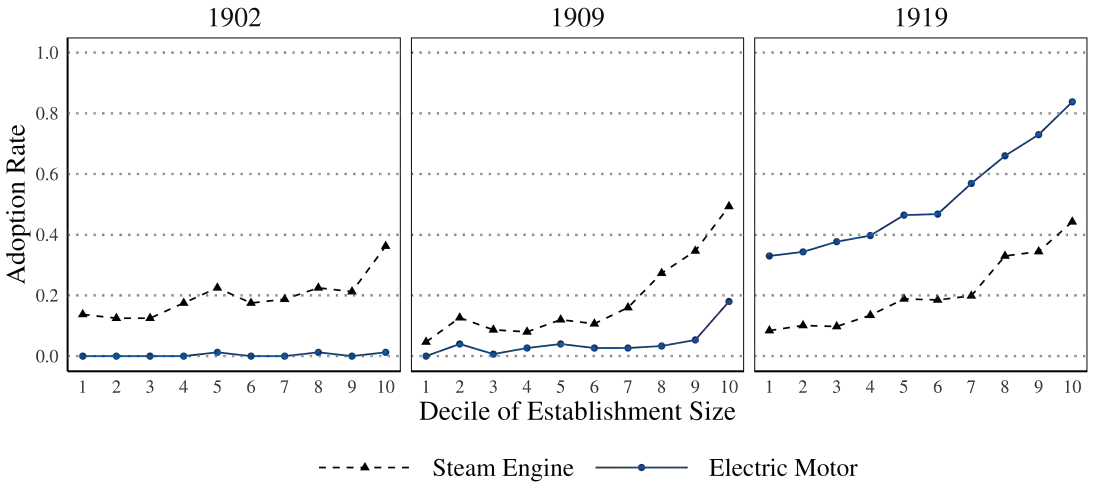
Back

Popularization of powered factory (Food products)



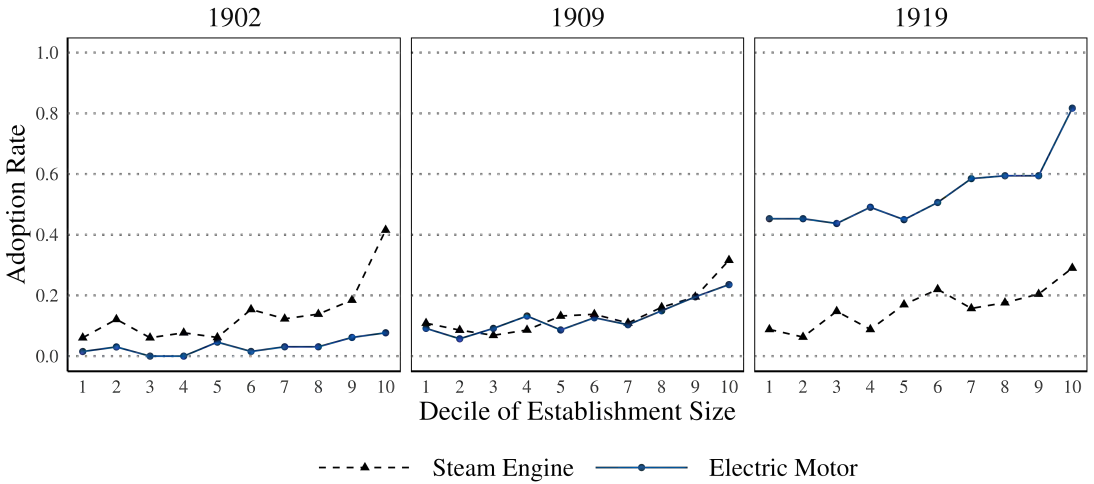
Back

Popularization of powered factory (Chemicals)



Back

Popularization of powered factory (Miscellaneous)



Back

Hydropower potential and economic activities

$$\begin{aligned} \mathrm{Y}_{it} = & \sum_{t \neq 1909} \beta_t \, \text{Hydropower Potential}_i \times \mathbf{1}\{\text{Year} = t\} + \\ & \sum_{t \neq 1909} \lambda_t \, \ln(\text{PopDens}_{i,1908}) \times \mathbf{1}\{\text{Year} = t\} + \\ & \sum_{t \neq 1909} \gamma_t \, \text{Geography}_i \times \mathbf{1}\{\text{Year} = t\} + \alpha_i + \delta_t + v_{it}, \end{aligned}$$

- i: municipality where electricity supply began after 1909.
- $t \in \{1902, 1909, 1916, 1919\}$: year.
- Y_{it}: # establishments.
- Hydropower potential$_i$: Suitability for hydropower generation.
- Geography$_i$: Area size, dist. to the coast, and dist. metropolis.
- (α_i, δ_t): municipality and year fixed effects.

Back

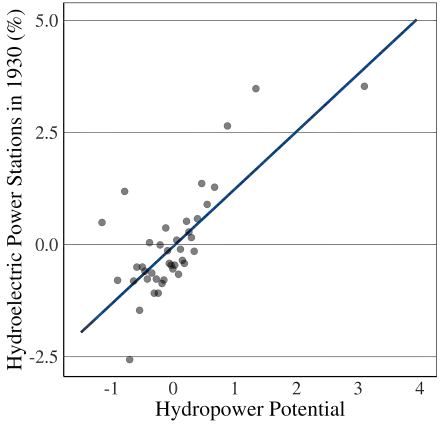
Hydropower potential matters only after the grid expansion

	Number of Establishments					
	Total			w/ Electric Motor		
	(1)	(2)	(3)	(4)	(5)	(6)
Hydropower Potential × 1902	-0.024	-0.020	-0.004	-0.001	-0.001	-0.001
	(0.022)	(0.023)	(0.023)	(0.001)	(0.001)	(0.001)
Hydropower Potential × 1916	0.015	0.023	0.018	0.047***	0.044***	0.040***
	(0.016)	(0.016)	(0.017)	(0.007)	(0.007)	(0.008)
Hydropower Potential × 1919	0.091**	0.090**	0.080**	0.101***	0.093***	0.081***
	(0.036)	(0.037)	(0.038)	(0.014)	(0.013)	(0.013)
Streamflow × Year FE		✓	✓		✓	✓
Ruggedness × Year FE			✓			✓
Observations	40,020	40,020	40,020	40,020	40,020	40,020
Adjusted R^2	0.68	0.68	0.68	0.34	0.34	0.34
Mean of dep.var	0.72	0.72	0.72	0.13	0.13	0.13

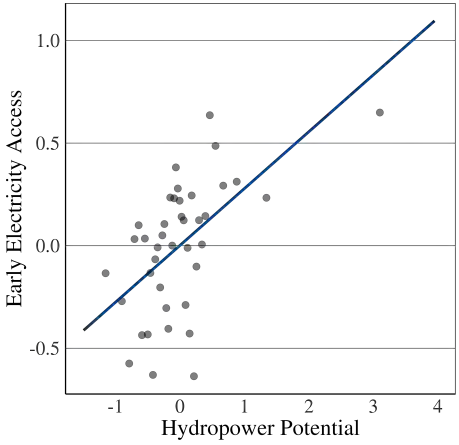
Notes: *, **, and *** indicate significance at the 10%, 5%, and 1% levels. Robust standard errors clustered at the municipality level are reported in parentheses.

▸ Back

Hydropower potential, hydroelectric generation, and early access



(a) Hydroelectric generation



(b) Early electricity access

Back

First stage

	Electricity Access in 1914			Early Electricity Access		
	(1)	(2)	(3)	(4)	(5)	(6)
Hydropower Potential	0.041***	0.042***	0.041***	0.216***	0.219***	0.250***
	(0.007)	(0.007)	(0.007)	(0.074)	(0.076)	(0.076)
Prefecture FE	✓	✓	✓	✓	✓	✓
Geography	✓	✓	✓	✓	✓	✓
Pop. density 1908	✓	✓	✓	✓	✓	✓
Streamflow		✓	✓		✓	✓
Ruggedness			✓			✓
Observations	10,005	10,005	10,005	10,005	10,005	10,005
Adjusted R^2	0.23	0.23	0.23	0.31	0.31	0.31
F-test (1st stage)	72.7	70.1	65.9	18.0	17.9	22.7
Mean of dep.var	0.23	0.23	0.23	15.7	15.7	15.7

Notes: Robust standard errors clustered by municipalities within 30km radius, following Conley (1999), are reported in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels.

▸ Back

Main result: Placebo test

	Δ Number of Establishments (1902-1909)				Demographics
	Total (1)	w/ Electric Motor (2)	Total (3)	w/ Electric Motor (4)	Δ Mnf. Workers (1902-1909) (5)
Electricity Access in 1914	0.395***	0.004**	0.176	0.012	24.4
	(0.083)	(0.002)	(0.693)	(0.016)	(28.0)
Model	OLS	OLS	IV	IV	IV
Prefecture FE	✓	✓	✓	✓	✓
Geography	✓	✓	✓	✓	✓
Pop. density 1908	✓	✓	✓	✓	✓
Streamflow	✓	✓	✓	✓	✓
Ruggedness	✓	✓	✓	✓	✓
Observations	10,005	10,005	10,005	10,005	10,005
First stage F-stat			65.9	65.9	65.9
Mean of dep.var	0.33	0.004	0.33	0.004	10.5

Notes: Robust standard errors clustered by municipalities within 30km radius, following Conley (1999), are reported in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels.

Back

Main result: Railway access

	Δ Number of Establishments (1909-1919)				Demographics	
	Total	w/ Electric Motor	Total	w/ Electric Motor	Δ Mnf. Workers (1909-1919)	Δ Pop. (1908-1918)
	(1)	(2)	(3)	(4)	(5)	(6)
Electricity Access in 1914	0.298***	0.551***	2.02*	1.29***	122.5***	156.0
	(0.088)	(0.062)	(1.04)	(0.409)	(44.7)	(376.8)
Δ Railway Access	-0.038	-0.034	0.036	-0.002	2.19	-28.4
	(0.044)	(0.026)	(0.070)	(0.032)	(3.13)	(28.1)
Model	OLS	OLS	IV	IV	IV	IV
Prefecture FE	✓	✓	✓	✓	✓	✓
Geography	✓	✓	✓	✓	✓	✓
Pop. density 1908	✓	✓	✓	✓	✓	✓
Streamflow	✓	✓	✓	✓	✓	✓
Ruggedness	✓	✓	✓	✓	✓	✓
Observations	10,005	10,005	10,005	10,005	10,005	9,991
First stage F-stat			64.6	64.6	64.6	65.5
Mean of dep.var	0.30	0.36	0.30	0.36	24.7	228.1

Notes: Robust standard errors clustered by municipalities within 30km radius, following Conley (1999), are reported in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels.

▸ Back

Main result: Infrastructure investment

	Δ Number of Establishments (1909-1919)				Demographics	
	Total (1)	w/ Electric Motor (2)	Total (3)	w/ Electric Motor (4)	Δ Mnf. Workers (1909-1919) (5)	Δ Pop. (1908-1918) (6)
Electricity Access in 1914	0.328***	0.560***	1.34*	1.32***	90.0**	121.1
	(0.090)	(0.064)	(0.771)	(0.395)	(40.8)	(357.6)
Model	OLS	OLS	IV	IV	IV	IV
Prefecture FE	✓	✓	✓	✓	✓	✓
Geography	✓	✓	✓	✓	✓	✓
Pop. density 1908	✓	✓	✓	✓	✓	✓
Streamflow	✓	✓	✓	✓	✓	✓
Ruggedness	✓	✓	✓	✓	✓	✓
Observations	9,864	9,864	9,864	9,864	9,864	9,850
First stage F-stat			67.4	67.4	67.4	68.3
Mean of dep.var	0.30	0.37	0.30	0.37	24.5	224.3

Notes: Robust standard errors clustered by municipalities within 30km radius, following Conley (1999), are reported in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels.

Back

Long-run effect: Economic activities today

	Num. of Firms		Num. of Emp.		Ave. Sales		Sales/Emp.	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Early Electricity Access	0.057***	0.158*	0.066***	0.185*	0.024***	0.095*	0.010***	0.067*
	(0.004)	(0.084)	(0.005)	(0.103)	(0.003)	(0.054)	(0.002)	(0.039)
Model	OLS	IV	OLS	IV	OLS	IV	OLS	IV
Prefecture FE	✓	✓	✓	✓	✓	✓	✓	✓
Geography	✓	✓	✓	✓	✓	✓	✓	✓
Pop. density 1908	✓	✓	✓	✓	✓	✓	✓	✓
Streamflow	✓	✓	✓	✓	✓	✓	✓	✓
Ruggedness	✓	✓	✓	✓	✓	✓	✓	✓
Observations	9,852	9,852	9,474	9,474	9,852	9,852	9,474	9,474
First stage F-stat		26.4		29.6		26.4		29.6
Mean of dep.var	3.4	3.4	5.0	5.0	7.8	7.8	6.3	6.3

Notes: Robust standard errors clustered by municipalities within 30km radius, following Conley (1999), are reported in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels.

▸ Back