The long-run gains from the early adoption of electricity

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HSE Seminar
Moscow, 29th October 2020

Motivation

- The timing and intensity of technology adoption led to a drastic divergence in incomes across countries (Mokyr 1992; Comin & Hobijn 2010; Comin & Mestieri 2018).

- Solow-Paradox: The positive effect of new technologies within advanced economies has been hard to document.
  - Technology diffusion has been notoriously slow for many key innovations at first (Griliches 1957; Hall 2004).
  - And large advances in technology appear to initially disrupt economic growth (David 1989; Jovanovic & Rousseau 2005).
  - Availability of detailed data and endogeneity key problems here.

Research question

- Three key empirical questions:
  (1) Does the early adoption of new technologies lead to economic development?
  (2) Do differences in economic activity persist over time as new technologies become adopted widely?
  (3) What mechanisms can explain this persistent divergence in economic activity?

- I investigate this exploiting the geographical variation in the potential to produce electricity across Switzerland.

Historical setting

- Electricity in Switzerland provides an excellent setting:
  - At the forefront of electricity adoption with the USA till 1900s.
  - Adoption quasi-random due to reliance on waterpower.
  - After 1900, rapid expansion of the electricity grid. Access becomes universal.
- Areas as good as randomly exposed to electricity for the first 20 years.

Main results

- Early electricity adoption led to economic development:
  - One standard deviation higher exposure to electricity is associated with a 3% decrease (increase) in the agricultural (manufacturing) share from 1880-1900.
  - Effect on structural transformation and incomes persists up to today.

- Mechanisms:
  - The persistent effect is not explained by persistent differences in generation and use of electricity itself.
  - Rather early adoption sparked human capital accumulation and innovation.

Related literature

- Effect of **electrification during the early 20th century**: Kitchens (2014); Kitchens & Fishback (2015); Gaggl et al. (2019); Lewis & Severnini (2019); Molinder et al. (2019); Leknes & Modalsli (2020)

- The effect of **new technologies** on the accumulation of **human capital**: e.g. Galor & Moav (2006); Galor (2011); De Pleijt et al. (2018)

- **Long-run effect** of technology adoption: Juhasz (2018); Frank & Galor (2019); Lewis & Severini (2019)

Outline

- Introduction
- Historical context
- Empirical approach
- Data
- Results
- Conclusions

Brief historical context

- Electricity starting to be used economically from the 1880s onwards.
- Switzerland highest per capita usage at the start of the 20th century (Paquier 2006).
- Relying on waterpower due to the prohibitive cost of imported fossil fuels (Bossard 1916).
- Electricity and chemicals key drivers of the second industrial revolution (Landes 1969; Mokyr 1998).
- Many novel chemical production processes required electricity (e.g. production of chlor-alkali, calcium carbide).

Example waterpower plants

A) without embankment dam

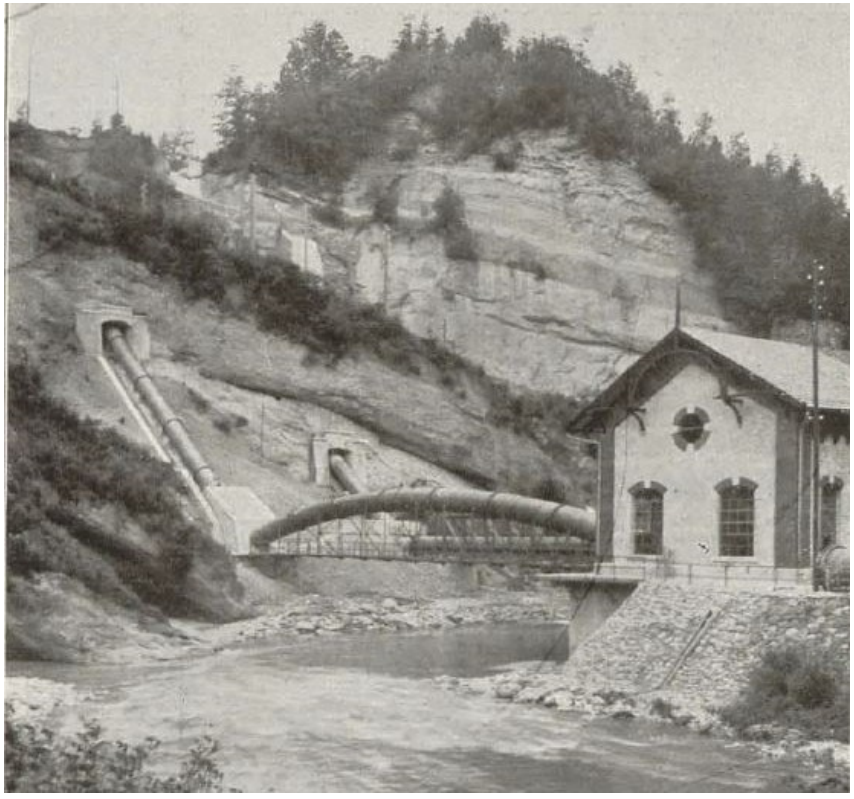


Figure: Water-power plant build in 1900 in Gospel with an average electricity generation of 2700kW.

▸ Area map

B) with embankment dam

Figure: Waterpower plant build in 1923 in Barberine with an electricity generation of over 15000kW and 39000000m^3 dam.

A historical example: Lonza

- Lonza was founded in 1897 in the small municipality of Gampel (population of 421 in 1880).
- Generation of electricity and production of calcium carbide.
- Expansion through opening new plant in nearby Visp (10km).
- 7th (48th overall) largest chemical company with 14,500 employees in 18 countries and Visp-site being the largest production and research site with 2800 employees (50% of population).
- Gampel site closed in 1964, however population remains extremely high-skilled (4.7% scientists).
- Legacy of educating the local workforce and innovation (including Nobel laureates like Paul Hermann Müller).

Empirical approach: Short-run

- Regression equation:

$$\Delta DEV_{d,1900-1880} = \beta \Delta E_{d,1900-1880} + \gamma' X_{d,1880} + \epsilon_d \quad (1)$$

  - $\Delta DEV_{d,1900-1880}$ change in economic development 1880-1900.
  - $\Delta E_{d,1900-1880}$ adoption electricity 1880-1900.
  - $X_{d,1880}$ vector of initial controls.

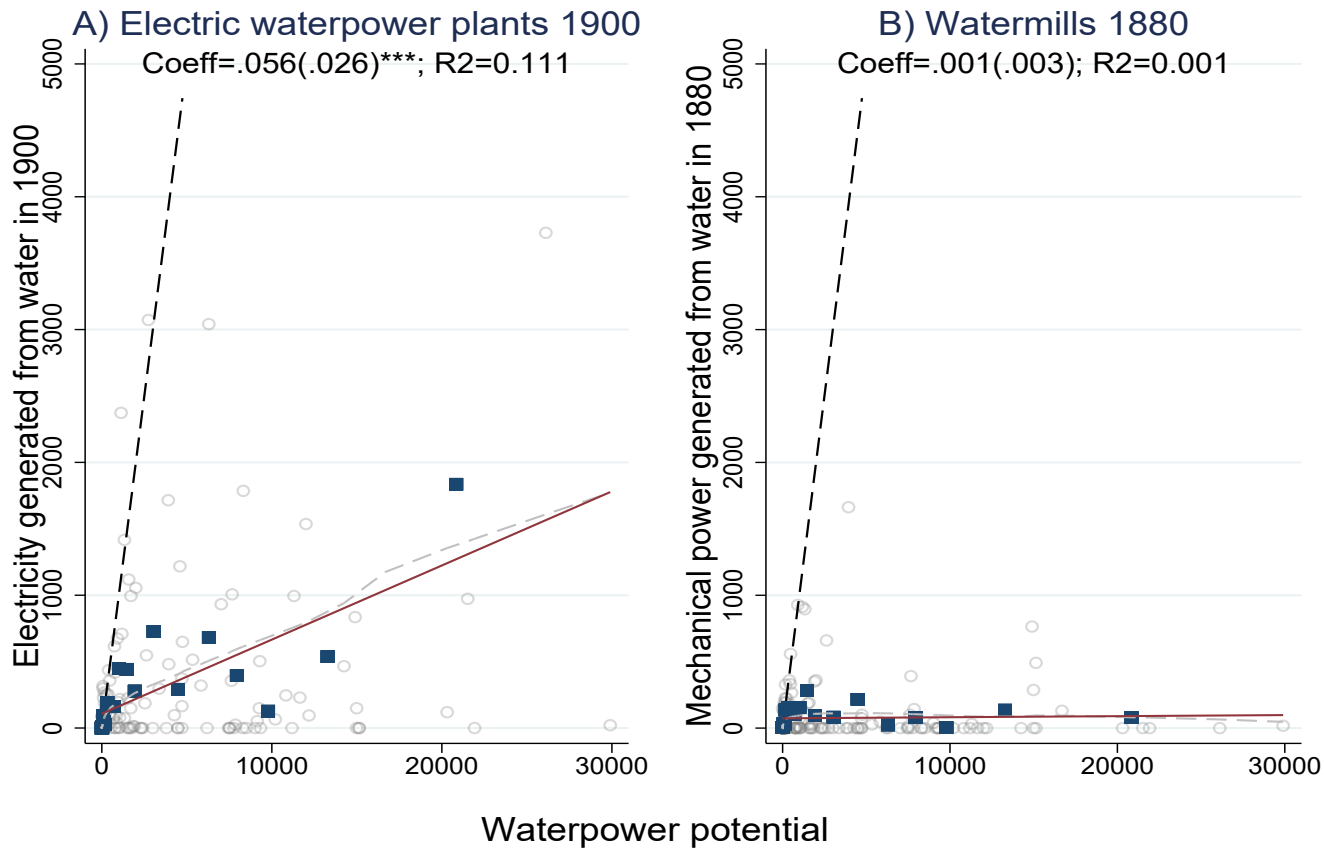
Threat to identification

- Electrification not random and depends on other factors:
  - Higher electricity demand in industrialising areas (upward-bias).
  - Industrializing areas unable to exploit water-power for electricity due to earlier allocated water-concessions (lasting 50-100 years) and rivers used for transport (downward-bias).
- Instrument the change in electricity produced per person from 1880-1900 with log water-power potential per person.

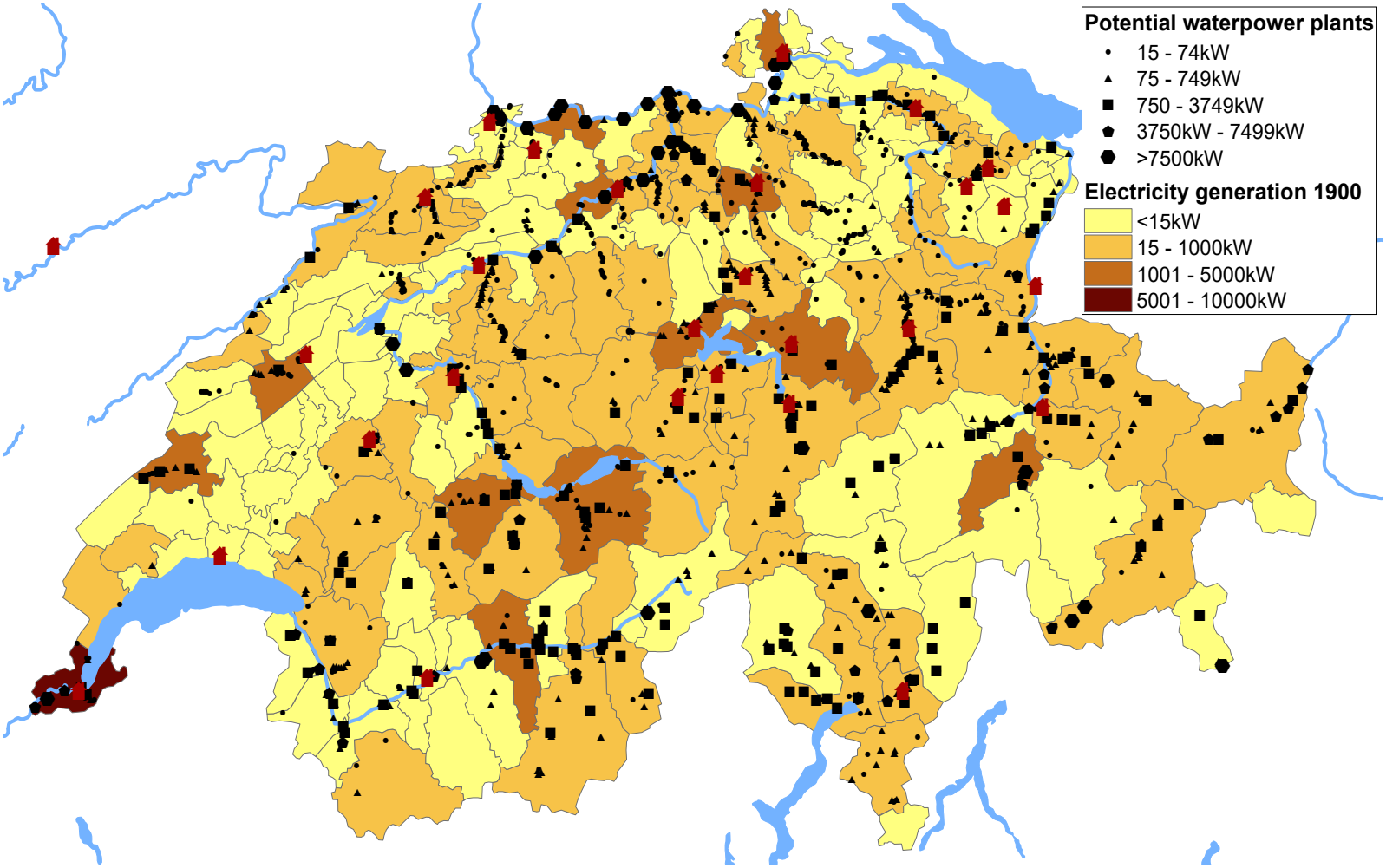
▸ Basel

Exclusion restriction

- Aims of engineers:
  - Maximise energy that could be generated.
  - Disregard existing development.
  - Disregard economic viability.
- Features irrelevant before ▸ Random ▸ Pre-trend:



Map of potential and generated electricity



▸ Source ▸ Example

Empirical approach: Long-run

- Regression equation:

$$\Delta DEV_{d,t-1880} = \beta_t \Delta E_{d,1900-1880} + \gamma_t \Delta E_{d,t-1900} + \gamma_t' X_{d,1880} + \epsilon_d \quad (2)$$

  - $\Delta DEV_{d,t-1880}$ change in economic development to period t.
  - $\Delta E_{d,1900-1880}$ early adoption electricity 1880-1900.
  - $\Delta E_{d,t-1900}$ controls for generation of electricity after 1900.
  - $X_{d,1880}$ vector of initial controls.

Data

- Data on exploited and potential water-power across Switzerland from the "Statistics of water-power of Switzerland in 1914".
  - Information on building/extension date and kW produced of water-power plants.
  - Information on type of energy usage.
  - Map of exploited and potential waterpower.

- Sectoral employment in 178 Swiss districts from the census for 1860-2011.

- Other data sources: Education level 1880-1910 (Swiss military exams); Electricity usage of firms in 1929 and 1955 (Census) and others.

▸ Summary stats ▸ Details I ▸ Details II

Short-run result

Effect of electricity on structural change 1880-1900

A. Agriculture (OLS)	(1)	(2)	(3)	(4)	(5)
Δ Electricity pp 1880-1900	-0.291***	-0.315***	-0.321***	-0.314***	-0.291***
	(0.041)	(0.050)	(0.057)	(0.057)	(0.042)
	[0.050]	[0.046]	[0.052]	[0.051]	[0.037]
Geographic controls		✓	✓	✓	✓
Economic controls			✓	✓	✓
Mechanical watermills				✓	✓
Region FE					✓
adj. R^2	0.048	0.089	0.090	0.097	0.131
N	178	178	178	178	178
B. Agriculture (IV)					
Δ Electricity pp 1880-1900	-0.500**	-0.756***	-0.731***	-0.734***	-0.625***
	(0.238)	(0.260)	(0.251)	(0.249)	(0.212)
First stage estimate	0.048***	0.051***	0.054***	0.054***	0.057***
	(0.008)	(0.011)	(0.012)	(0.012)	(0.014)
F-stat (1st stage)	36.56	20.51	19.96	19.98	16.66
Reduced form estimate	-0.024*	-0.038***	-0.039***	-0.039***	-0.036**
	(0.012)	(0.010)	(0.010)	(0.010)	(0.013)
C. Manufacturing (IV)					
Δ Electricity pp 1880-1900	0.417*	0.536**	0.570**	0.573**	0.532**
	(0.241)	(0.271)	(0.282)	(0.279)	(0.262)
D. Services (IV)					
Δ Electricity pp 1880-1900	0.083	0.220+	0.161	0.162	0.093
	(0.206)	(0.135)	(0.151)	(0.152)	(0.162)

▸ Additional controls ▸ Bias OLS

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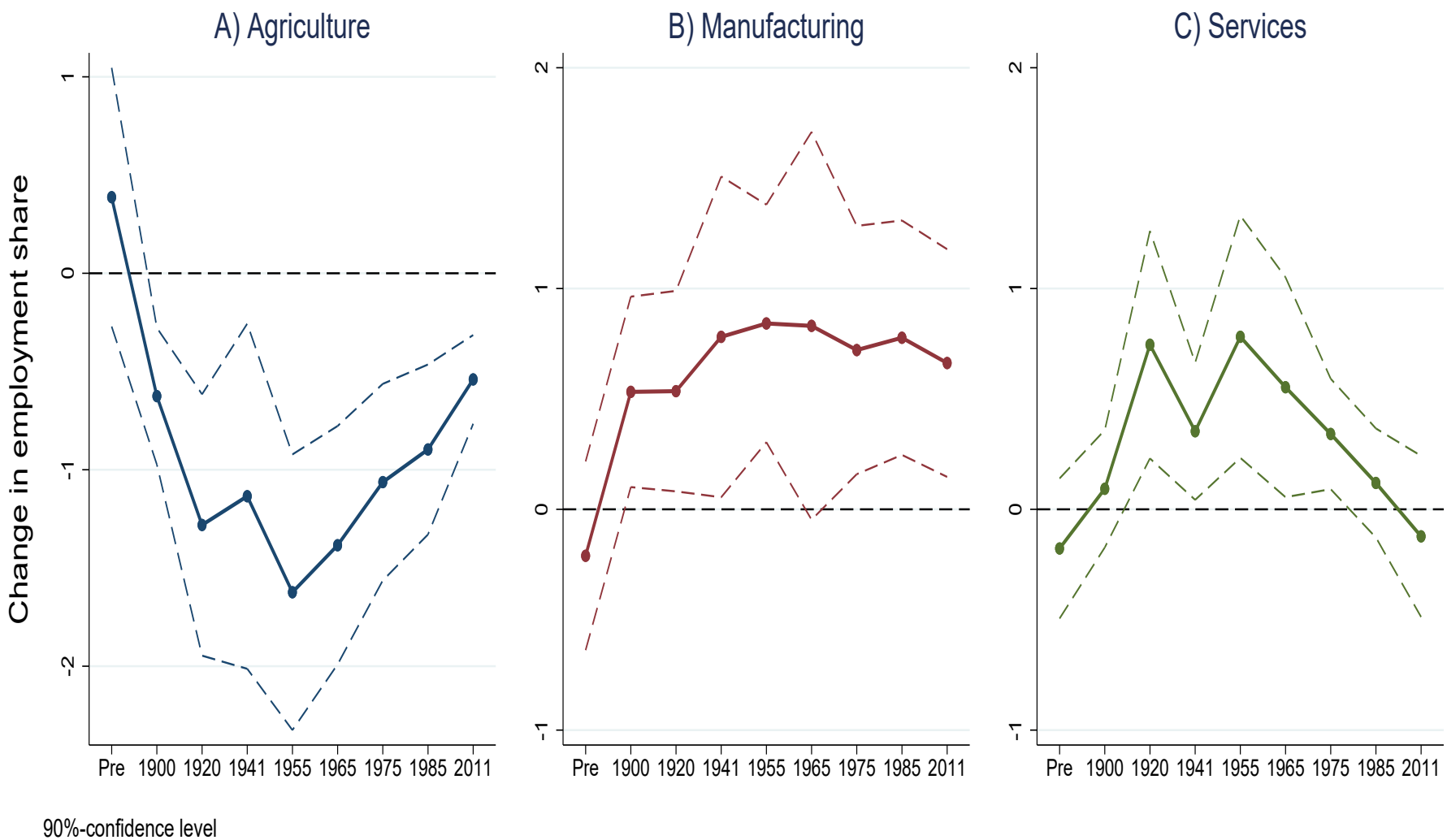
▸ Additional controls ▸ Bias OLS

Long-run result I

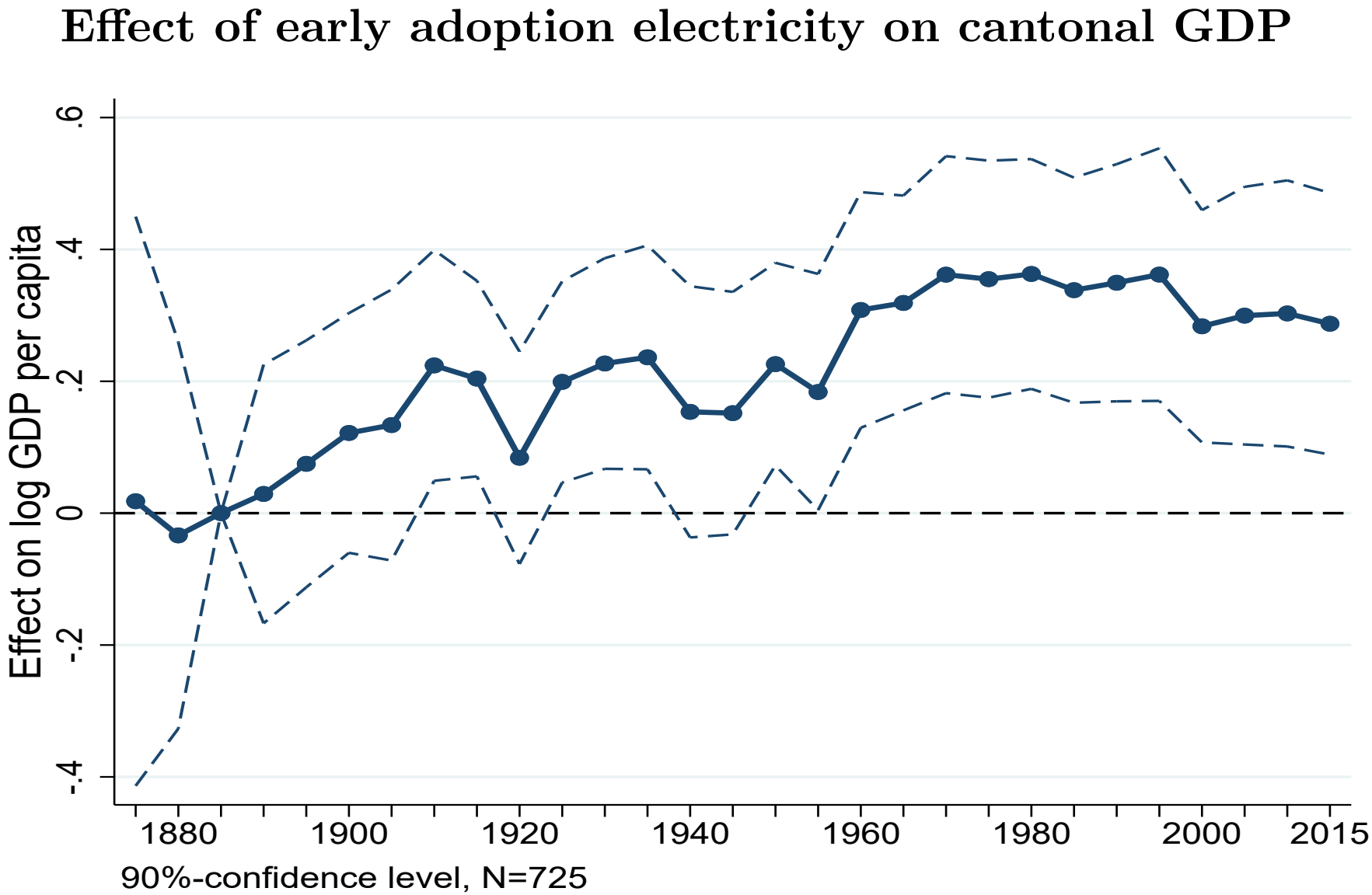
Effect of early adoption electricity on strucutural change



90%-confidence level

▸ Employment growth

Long-run result II



Current Outcomes

Effect of early electricity adoption on current outcomes

	Income		*Education*	
	Average	*Median*	*Secondary*	*Tertiary*
	(1)	(2)	(3)	(4)
Δ Electricity pp 1880-1900	42.543*	26.922*	0.405***	0.196***
	(25.777)	(14.460)	(0.146)	(0.036)
Controls	Yes	Yes	Yes	Yes
N	178	178	178	178

Summary mechanisms

- Potential mechanisms:
  - Persistent differences in technology adoption?
  - Agglomeration forces?
  - Human capital accumulation and innovation?
  - Role of infrastructure?

Mechanism: Which industries gained?

Effect of early electricity adoption by industry over time

	Generation	Mixed		Use of electricity only			
A. 1880-1900	Elec. (1)	Con. (2)	Mach. (3)	Chem. (4)	Text. (5)	Food (6)	Other (7)
Δ Electricity pp 1880-1900	0.037**	0.378*	-0.006	0.102**	0.135	-0.078***	-0.036
	(0.017)	(0.205)	(0.074)	(0.041)	(0.156)	(0.029)	(0.041)
B. 1880-1920							
Δ Electricity pp 1880-1900	0.066***	-0.009	-0.077	0.114***	0.354*	-0.067	0.105+
	(0.011)	(0.077)	(0.119)	(0.043)	(0.211)	(0.062)	(0.071)
C. 1880-1975							
Δ Electricity pp 1880-1900	0.138***	-0.174	-0.790***	0.604**	1.194***	-0.093	-0.156+
	(0.035)	(0.203)	(0.223)	(0.278)	(0.398)	(0.099)	(0.108)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	178	178	178	178	178	178	178

- Electricity generation not main driver of persistence!
- Development chemical industry consistent with luck of initial location and cumulative process of development (explains 1900: 47%, 1975: 72%).
- Textile industries (peaked by 1880) not consistent with economies of scale (inconsistent with e.g. Krugman 1991).

Mechanism: Electricity use

Long-run differences in electricity use

	Electricity use in kW per		
	District	Firm	Employee
A. 1929	(1)	(2)	(3)
Δ Electricity pp 1880-1900	6017.18	141.92	-6.92
	(8775.68)	(526.02)	(15.90)
B. 1955			
Δ Electricity pp 1880-1900	20655.16	25.24	-0.45
	(30241.94)	(38.77)	(7.03)
Controls	Yes	Yes	Yes
N	178	178	178

- Due to expansion of electricity grid no persistent differences in use of electricity (inconsistent with e.g. Comin & Mestieri 2018)
- Later expansion of electricity generation only affect employment in this sector ▸ Generation 1900-1920

Mechanism: Population Agglomeration I

Effect of electricity on employment and population growth

	Employment growth 1880-1900			
	All	Agriculture	Manufacturing	Services
	(1)	(2)	(3)	(4)
Δ Electricity pp 1880-1900	1.242***	-0.553***	2.527**	1.203+
	(0.456)	(0.180)	(1.255)	(0.839)
	Population growth 1880-1900			
	Municipality	Canton	Swiss	Foreign
	(5)	(6)	(7)	(8)
Δ Electricity pp 1880-1900	0.199	0.425	-1.381	3.264
	(0.282)	(0.516)	(2.604)	(2.986)
Controls	Yes	Yes	Yes	Yes
N	178	178	178	178

- Increase in local labour force participation.
- But no effect on local population growth or in-migration (inconsistent with e.g. Bleakley & Lin 2012).

Mechanism: Population Agglomeration II

Effect of electricity on employment growth

	Employment growth rate		
A. Overall	1880-1900 (1)	1900-1920 (2)	1920-1941 (3)
Δ Electricity pp 1880-1900	1.242***	0.986*	-0.040
	(0.456)	(0.542)	(0.313)
B. Male			
Δ Electricity pp 1880-1900	1.549***	-0.369	-0.298
	(0.464)	(0.576)	(0.322)
C. Female			
Δ Electricity pp 1880-1900	0.021	2.105**	0.653
	(0.202)	(0.966)	(0.728)
Controls	Yes	Yes	Yes
N	178	178	178

- First male than female employment growth.
- But employment growth stagnates as local labour reserves are exhausted.

Mechanism: Human-capital & innovation I

Effect of electricity on primary and secondary education

A. Secondary education 1880-1900	Overall (1)	Reading (2)	Writing (3)	Math (4)	General (5)
Δ Electricity pp 1880-1900	0.530*	0.476+	0.667**	0.064	0.713**
	(0.306)	(0.351)	(0.338)	(0.358)	(0.310)
B. Secondary education 1880-1910					
Δ Electricity pp 1880-1900	0.932**	0.677*	0.784*	1.178*	1.089**
	(0.449)	(0.353)	(0.404)	(0.696)	(0.449)
C. Primary education 1880-1900					
Δ Electricity pp 1880-1900	0.088	-0.353**	0.154	0.037	0.310
	(0.316)	(0.178)	(0.460)	(0.327)	(0.612)
D. Primary education 1880-1910					
Δ Electricity pp 1880-1900	0.158	-0.259+	0.246	0.517	0.129
	(0.232)	(0.168)	(0.341)	(0.479)	(0.314)
Controls	Yes	Yes	Yes	Yes	Yes
N	178	178	178	178	178

- Increase in human-capital formation and endogenous economic growth (consistent with e.g. Romer 1990; Goldin & Katz 2001; Galor 2011).

Mechanism: Human-capital & innovation II

Effect of electricity on dual education

	All districts			Population centres		
A. Students	Dual (1)	Voc. (2)	Poly. (3)	Dual (4)	Voc. (5)	Poly. (6)
Δ Electricity pp 1880-1900	0.717^{+}	0.375	0.343^{+}	5.737^{**}	5.345^{**}	0.392
	(0.531)	(0.356)	(0.222)	(2.450)	(2.458)	(1.654)
B. Schools						
Δ Electricity pp 1880-1900	2.183	0.395	1.787	28.576^{**}	10.891^{*}	17.684^{**}
	(2.342)	(1.070)	(1.475)	(11.271)	(6.502)	(7.593)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
N	178	178	178	63	63	63

- Increase in supply of schooling (due to employer provision or local municipality revenue increase).

▸ Spending

Mechanism: Human-capital & innovation III

Effect of electricity on education demand

	1902 (1)	1963 (2)	1964 (3)	1973 (4)	1973 (5)	1978 (6)
Δ Electricity pp 1880-1900	0.940^{+}	0.168^{+}	0.483^{***}	1.790^{***}	1.256^{***}	1.171^{***}
	(0.667)	(0.117)	(0.131)	(0.674)	(0.304)	(0.274)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
N	178	178	178	178	178	178

- Local opportunity also increases the demand for education. Complementary process of development & demise class structure as e.g. Galor & Moav (2006).

Mechanism: Human-capital & innovation IV

Effect of early electricity adoption on innovation today

	All patents (1)	Before 2000 (2)	After 2000 (3)	City (4)	Town (5)	Rural (6)
Δ Electricity pp 1880-1900	0.111***	0.053***	0.057***	0.003	0.042**	0.066**
	(0.033)	(0.016)	(0.021)	(0.009)	(0.020)	(0.029)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
N	178	178	178	178	178	178

- This translates into increased innovation, which drives further economic growth.
- Effect randomly allocated and larger in remote areas (< 10000)! Skilled employment and innovation in remote areas appears puzzling (see e.g. Eaton & Kortum 2002).

Mechanism: Complementary Infrastructure I

Effect of electricity on infrastructure today

	Operation points (per km^2) (1)	Tunnels (per km^2) (2)	Train journeys (per person) (3)
Δ Electricity pp 1880-1900	0.262^{*}	0.056^{*}	3.762^{***}
	(0.151)	(0.030)	(1.253)
Controls	Yes	Yes	Yes
N	178	178	178

- Infrastructure network adjusts and better integrates previously remote areas (see also Dell & Olken 2020).

Mechanism: Complementary Infrastructure II

Effect of electricity on infrastructure demand

	1877 (7)	1891 (8)	1897 (9)	1927 (10)	1945 (11)	1987 (12)
Δ Electricity pp 1880-1900	-0.696	-0.608	0.091	0.483*	1.178***	1.699***
	(0.605)	(0.547)	(0.703)	(0.265)	(0.361)	(0.411)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
N	178	178	178	178	178	178

- This is also reflected in a change in local perceptions.

Summary mechanisms

- Unsupported mechanisms:
  - Persistent differences in the use of electricity.
  - Extension electricity generation.
  - Agglomeration forces.

- Supported mechanisms:
  - Increase in human capital formation and innovation.
  - Complementary adjustment in infrastructure network.
  - Consistent with highly innovative manufacturing firms in rather remote areas across Central Europe.
  - Interesting difference to development in the USA: role of distance (i.e. clustering more important) or immigration (i.e. coordination devices)?

Conclusion

- Already in the late 19th century the adoption of electricity increased industrialization.
- The economic effect of the early adoption of electricity persists (and increased) up to today.
- The main mechanism appears increased human capital accumulation and future innovation.

Thank You!

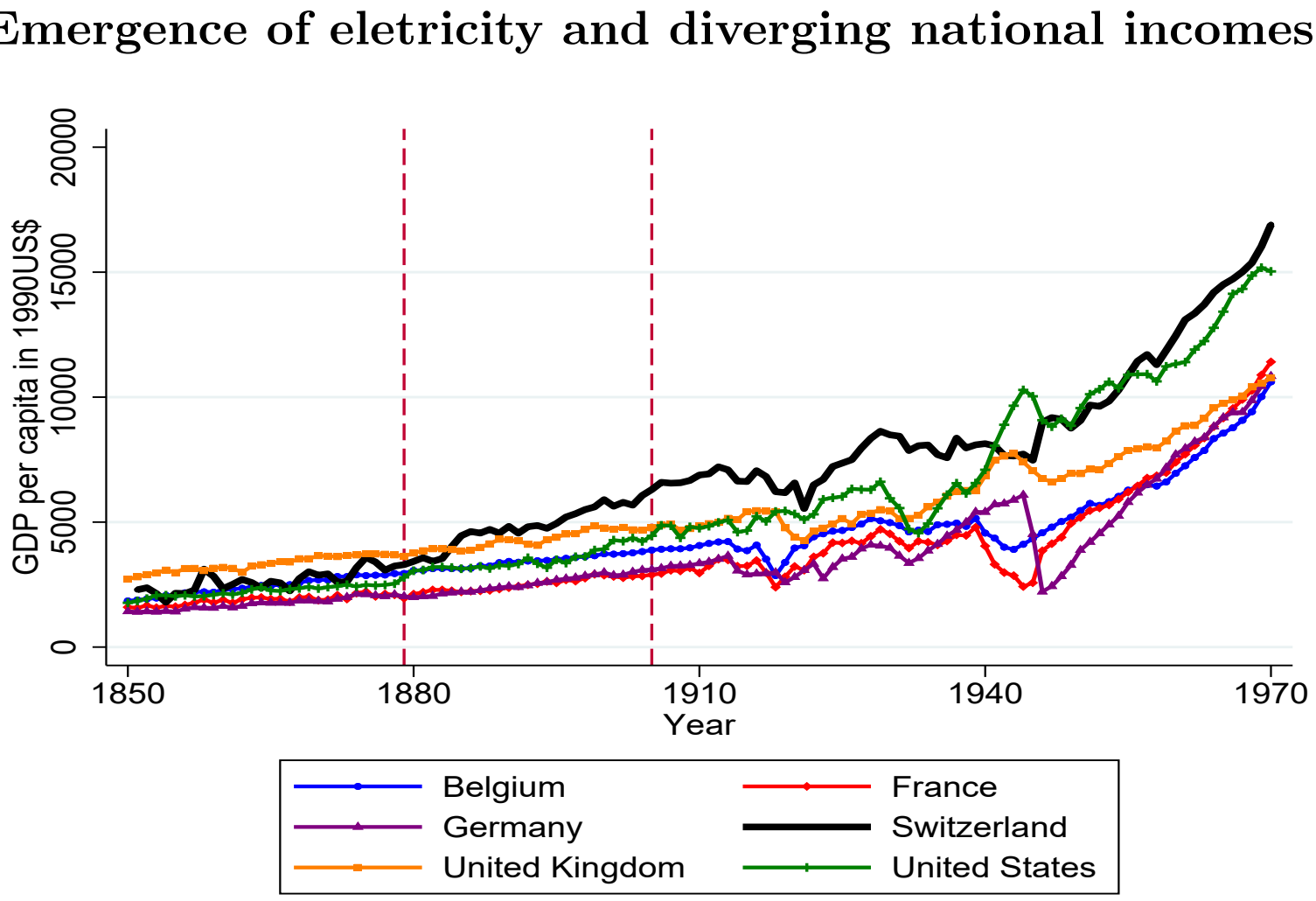
Summary stats

Summary statistics for the main variables used.

	Mean	Std. dev.	25th Perc.	75th Perc.	Valid obs.
Change agricultural share 1880-1900	-0.07	0.07	-0.10	-0.02	178
Change manufacturing share 1880-1900	0.05	0.05	0.01	0.08	178
Change services share 1880-1900	0.02	0.04	0.01	0.03	178
Change electricity 1880-1900	0.02	0.05	0.00	0.01	178
Log water-power potential	0.23	0.40	0.00	0.24	178
Altitude (km)	0.96	0.56	0.53	1.22	178
Longitude	8.08	0.98	7.27	8.89	178
Latitude	46.98	0.45	46.62	47.37	178
Share agricultural employment (1880)	0.49	0.20	0.34	0.65	178
Population density (1880)	0.13	0.35	0.04	0.13	178
Average educ. grade (1880)	2.64	0.39	2.35	2.89	178
Mechanical waterpower per person (1880)	0.00	0.01	0.00	0.00	178

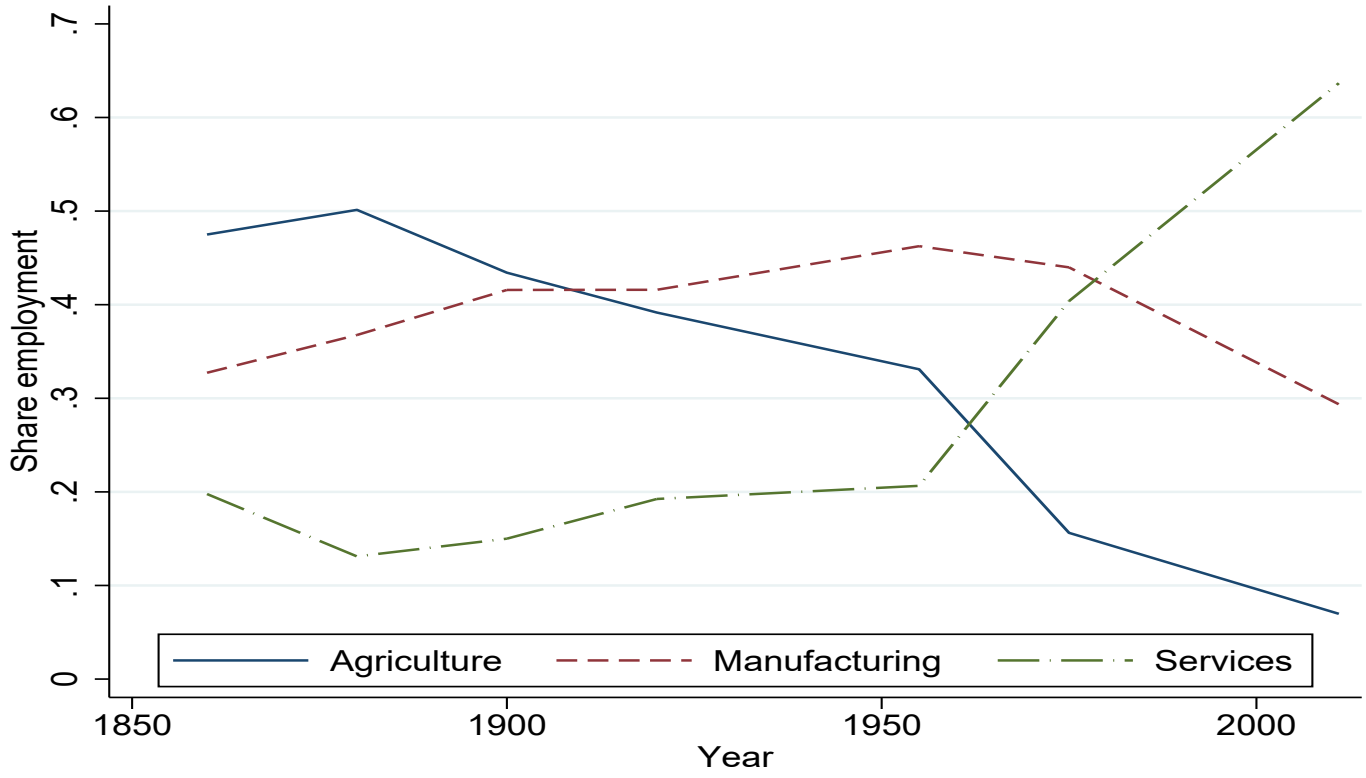
▸ Back

Cross country GDP



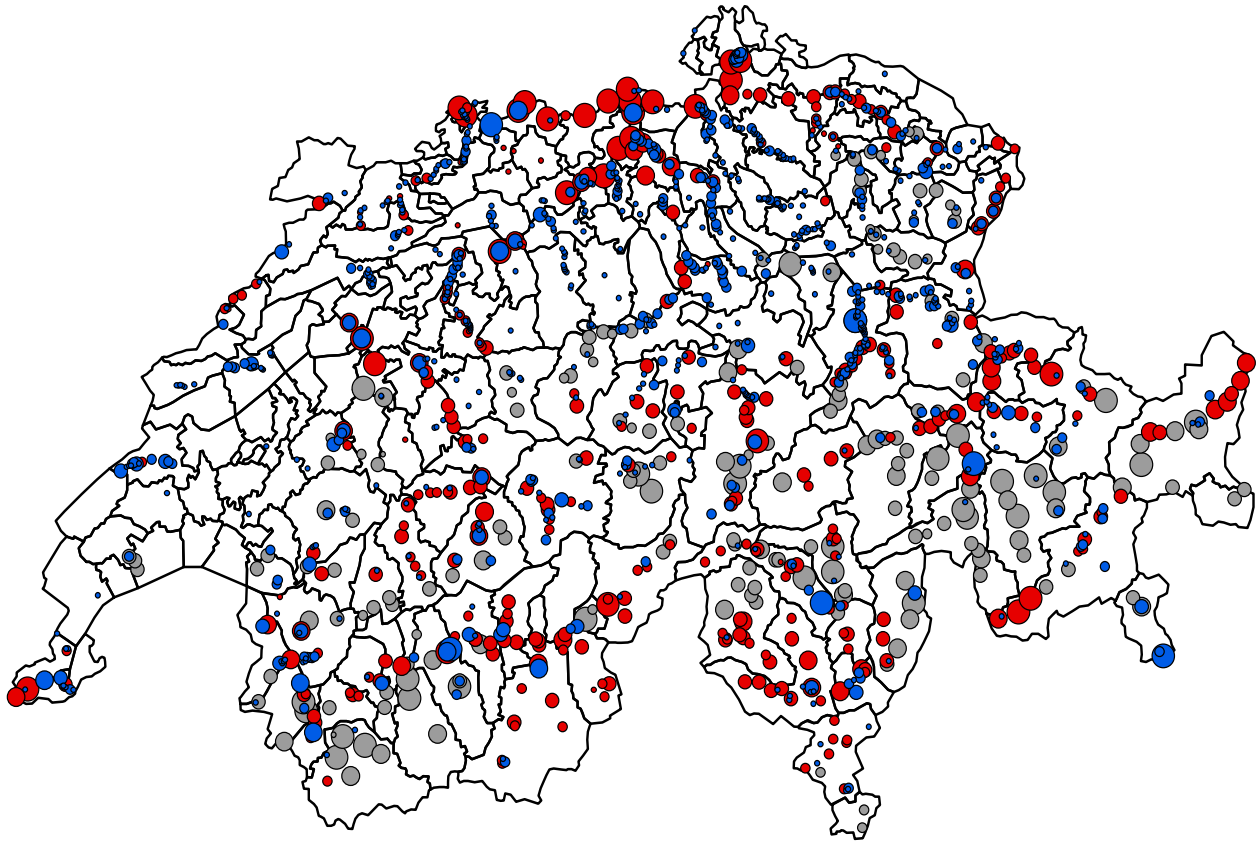
Real GDP per capita in 1990US$ across leading industrial countries from 1850-1970. Source: Madison Project Database (2018).

Employment across sectors



The figure depicts the share of employment in (i) agriculture, (ii) mining and manufacturing and (iii) services for 1860, 1880, 1900, 1920, 1955, 1975, and 2011. The share of employment reported is the average across the 178 districts in the sample.

Distribution Waterpower



Blue dots exploited water-power, red dots potential water-power, grey dots require a dam. Size of circle representing (i) 20-99HP, (ii) 100-999HP, (iii) 1000-4999HP, (iv) 5000-9999HP and (v) above 10000HP. Source: Statistics of water-power of Switzerland 1914.

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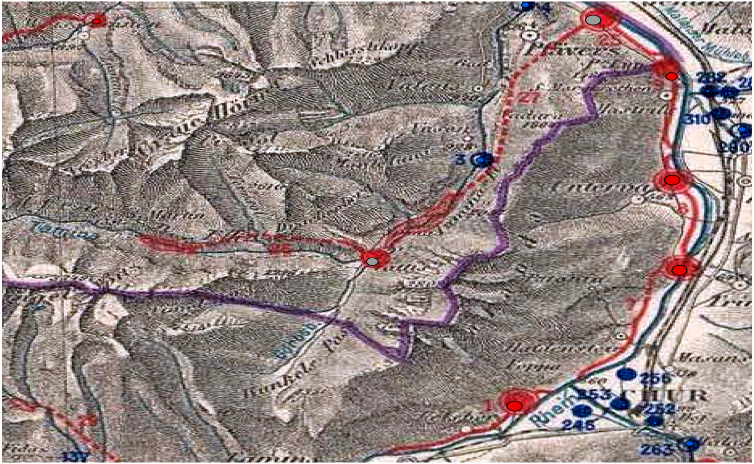
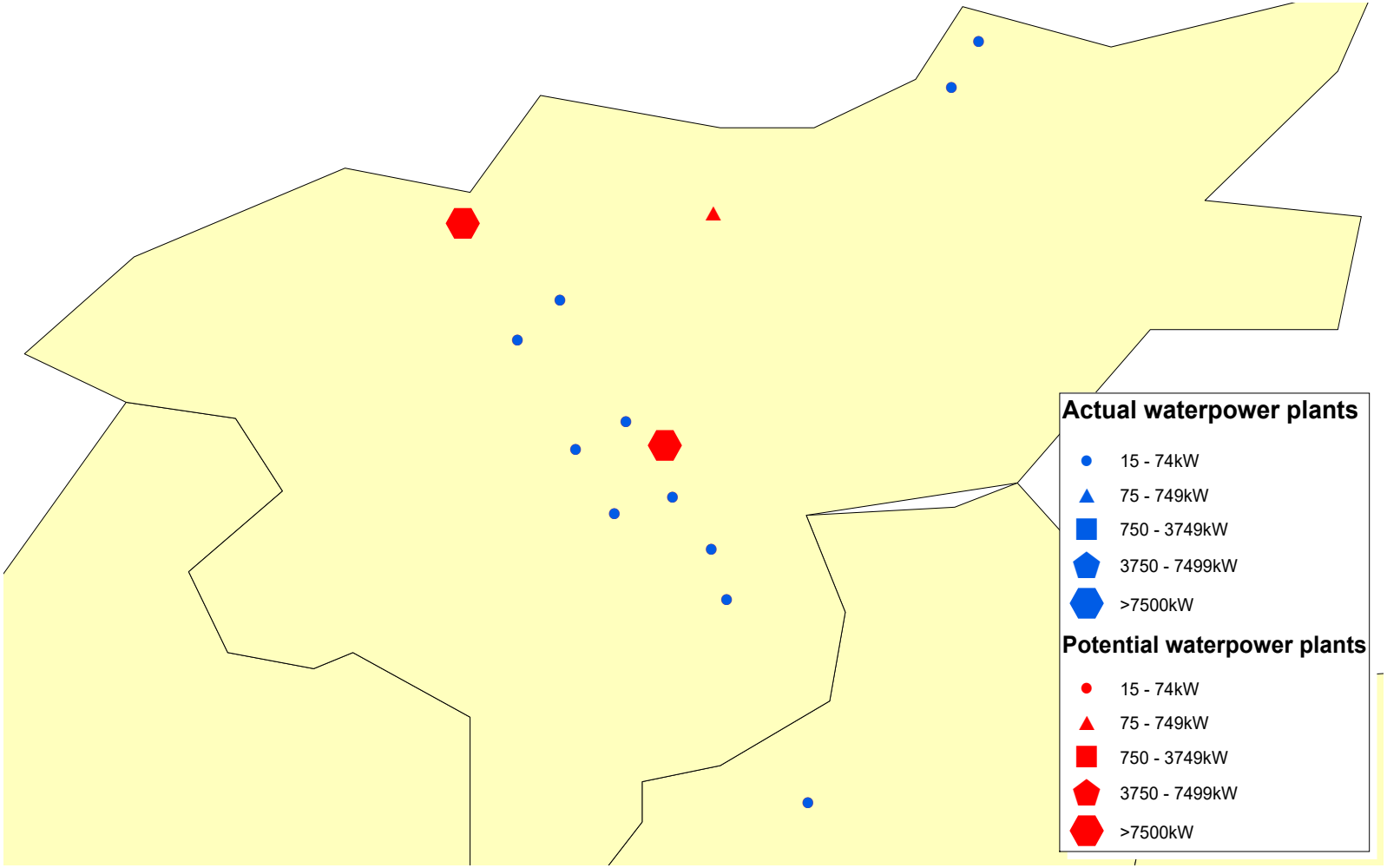
Raw Data



Blue dots exploited water-power, red dots potential water-power, grey dots require a dam. Size of circle representing (i) 20-99HP, (ii) 100-999HP, (iii) 1000-4999HP, (iv) 5000-9999HP and (v) above 10000HP.

Example Basel



Waterpower plants and potential in the city of Basel. Most of the exploited waterpower is still watermills using mechanical energy.

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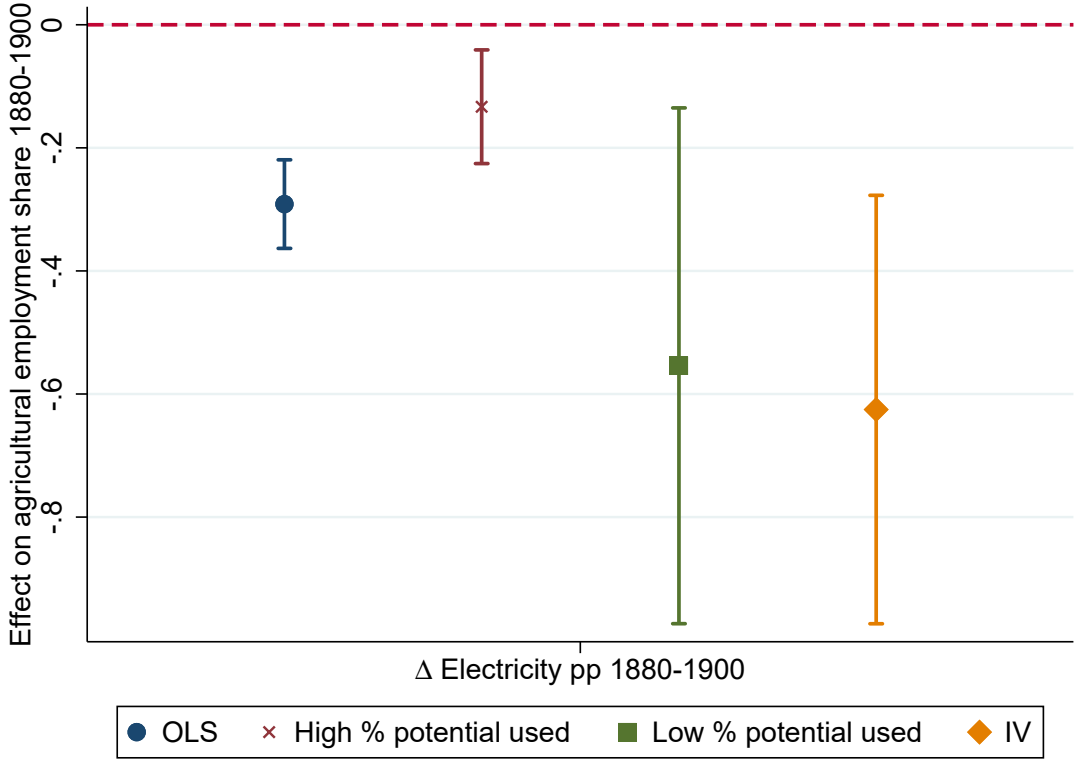
Evidence on source of bias in the OLS



This figure highlights that the downward bias in magnitude in the OLS is due to areas that utilize a large share of their potential for electricity generation ($> 20\%$) as they have a smaller marginal effect from adoption compared to those areas that are only able to utilize a small share ($< 20\%$). N=178; 66; 112; 178 Back

Example waterpower plants

A) without embankment dam

Figure: Water-power plant in Gospel (1:10000). Back

B) with embankment dam

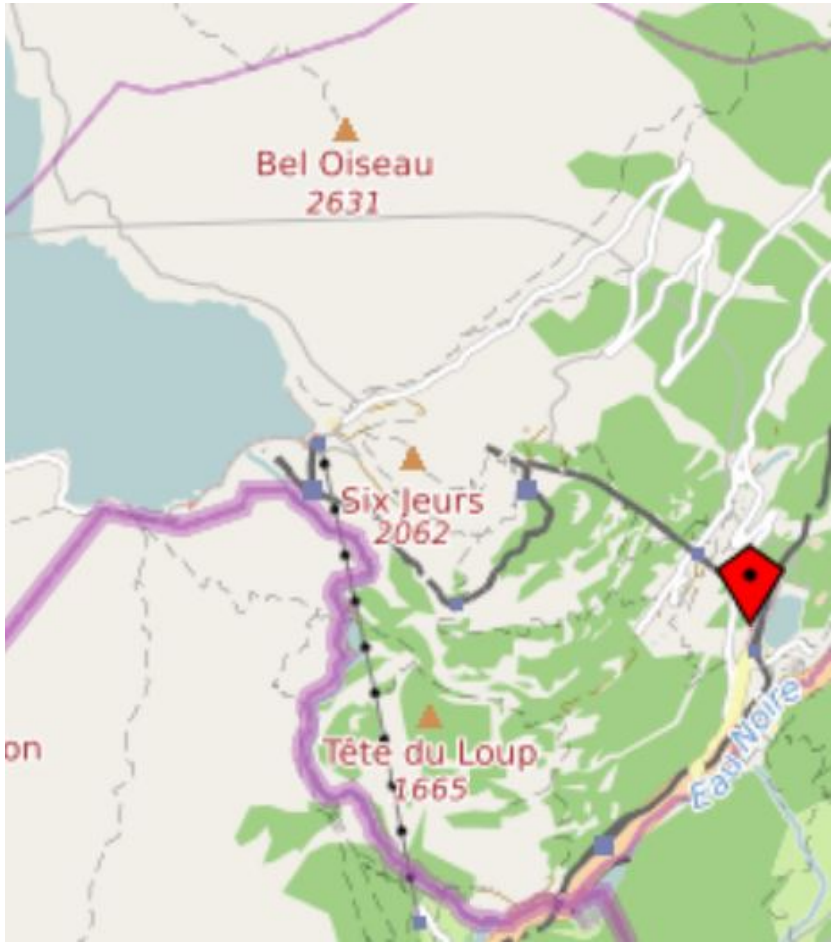
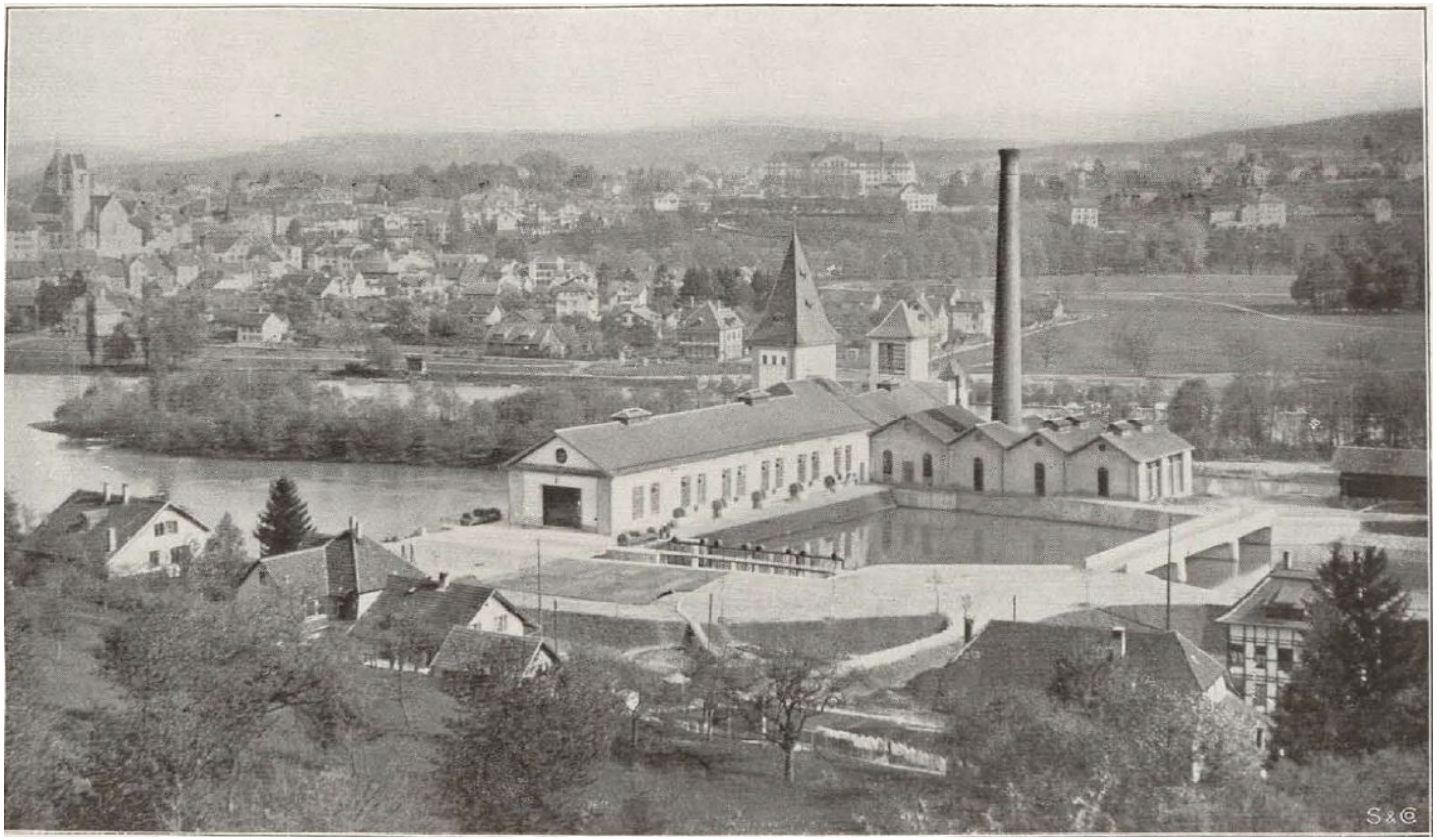


Figure: Water-power plant in Barberine (1:1000000).

Example 1



Waterpower plant in Aarau and Gösgen build in 1894 and extended in 1912 owned by the municipality of Aarau with an average electricity production of 940HP. Concession till 1990. Source: Statistics of water-power of Switzerland, 1914.

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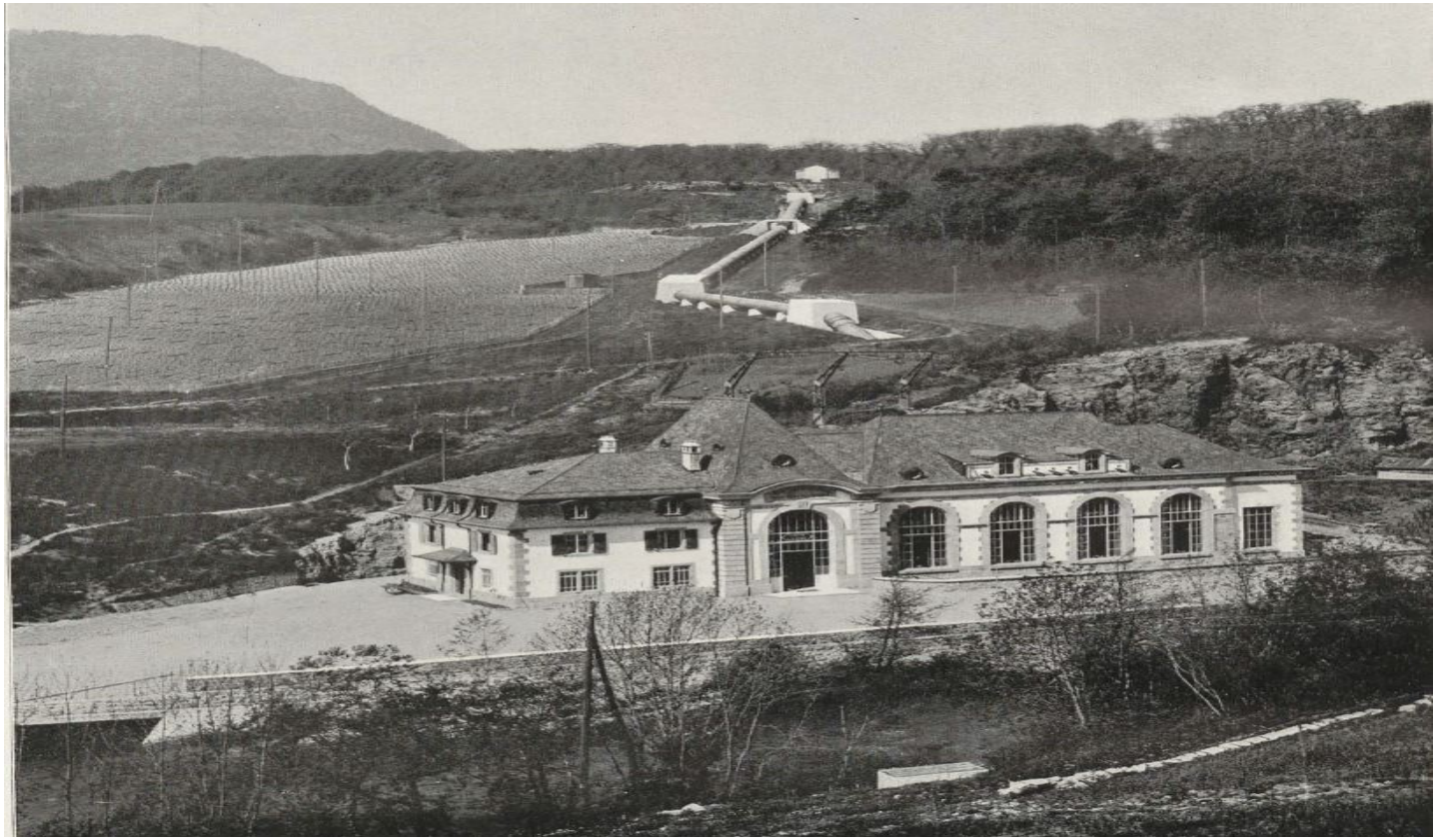
Example 2



Waterpower plant in Prés du Chanet build in 1895 and extended in 1914 owned by the municipality of Neuchätel in the Boudry district with an average electricity production of 3000HP. Concession till 1989. Source: Statistics of water-power of Switzerland, 1914.

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Treatment assignment

Comparison areas with and without electricity potential

	Control		Treatment			
Variable	Mean	N	Mean	N	Diff	P value
Panel A. Difference between no-potential vs. any potential						
Share agricultural employment (1880)	0.53	29	0.49	149	0.041	
Share manufacturing employment (1880)	0.35	29	0.40	149	-0.047	
Share services employment (1880)	0.14	29	0.13	149	0.006	
Altitude (km)	0.75	29	1.00	149	-0.246	**
Longitude	7.55	29	8.19	149	-0.633	***
Latitude	46.93	29	46.99	149	-0.064	
Panel B. Difference between no-potential vs. top 33% of potential						
Share agricultural employment (1880)	0.53	29	0.57	61	-0.041	
Share manufacturing employment (1880)	0.35	29	0.31	61	0.038	
Share services employment (1880)	0.14	29	0.14	61	-0.001	
Altitude (km)	0.75	29	1.27	61	-0.522	***
Longitude	7.55	29	8.23	61	-0.680	***
Latitude	46.93	29	46.79	61	0.136	

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

T-test between means in treatment and control for instrument.

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Pre-Trend

Pre-trend 1860-1880

	Agriculture		Manufacturing		Services	
	(1)	(2)	(3)	(4)	(5)	(6)
Δ Electricity pp 1880-1900	0.087	0.388	-0.348	-0.210	0.260	-0.177
	(0.552)	(0.400)	(0.436)	(0.260)	(0.320)	(0.193)
F-stat (1st stage)	37.76	18.39	37.76	18.39	37.76	18.39
Controls	No	Yes	No	Yes	No	Yes
N	177	177	177	177	177	177

Pre-trend effect of electricity adoption 1880-1900 on development 1860-1880. 1860 initial controls.

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	Additional human characteristics					Additional geographic controls					All
A. OLS	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Electricity	-0.305***	-0.298***	-0.305***	-0.288***	-0.280***	-0.294***	-0.284***	-0.291***	-0.290***	-0.273***	-0.269***
	(0.042)	(0.047)	(0.046)	(0.044)	(0.033)	(0.038)	(0.040)	(0.044)	(0.044)	(0.049)	(0.052)
Share math	-0.104+										-0.067
	(0.065)										(0.083)
Share Cath.		0.008									0.016
		(0.022)									(0.030)
Share Jew		-0.914									-0.360
		(0.792)									(0.781)
Share Rom.			-0.070+								0.013
			(0.046)								(0.029)
Share Ital.			-0.012								0.054
			(0.040)								(0.053)
Share Fr.			-0.017								-0.009
			(0.022)								(0.049)
Liberal				0.016							0.092+
				(0.016)							(0.056)
Sonderbund				0.031+							0.199***
				(0.019)							(0.049)
Canton FE					Yes						Yes
					✓						✓
Cropland						0.085***					0.035
						(0.020)					(0.030)
River							-0.017**				-0.006
							(0.006)				(0.008)
Water flow								-0.001***			-0.001***
								(0.000)			(0.000)
Alpine									-0.007		-0.004
									(0.016)		(0.022)
Po Basin									0.055***		0.073***
									(0.004)		(0.012)
Rugged										-0.093*	-0.096
										(0.047)	(0.086)
B. IV											
Electricity	-0.661***	-0.575***	-0.595***	-0.585***	-0.497*	-0.600***	-0.512***	-0.546***	-0.635***	-0.601***	-0.406*
	(0.240)	(0.211)	(0.178)	(0.224)	(0.281)	(0.211)	(0.193)	(0.194)	(0.210)	(0.221)	(0.210)

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Employment growth by sector

Effect electricity on sectoral employment growth

Dependent Variable: Employment growth rate

	1880-1920	1920-1975	1975-2011
	(1)	(2)	(3)
Panel A. Agriculture			
Change electricity 1880-1900	-0.922**	-0.333*	0.147
	(0.421)	(0.183)	(0.281)
Panel B. Manufacturing			
Change electricity 1880-1900	6.103**	7.819**	0.881
	(2.608)	(3.815)	(0.866)
Panel C. Services			
Change electricity 1880-1900	7.661**	2.452	-0.515
	(3.142)	(1.999)	(1.805)
Controls	Yes	Yes	Yes
N	178	178	178

Robust standard errors in parentheses are clustered at the cantonal level
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Electricity adoption 1900-1920

Electricity adoption and industry employment 1900-1920

	Elec. (1)	Con. (2)	Metal (3)	Chem. (4)	Text. (5)	Food (6)	Others (7)
Δ Electricity pp 1900-1920	0.006***	-0.001	-0.001	0.001	0.002	-0.001	-0.002+
	(0.000)	(0.004)	(0.004)	(0.002)	(0.004)	(0.001)	(0.001)

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Education spending

Effect early electricity adoption on education spending

Dependent Variable: Change in education spending 1887-1900

	Primary		Secondary	
	Pupils	Expenditure	Pupils	Expenditure
Change electricity 1880-1900	0.804	0.730*	0.059	9.846**
	(0.630)	(0.406)	(0.107)	(4.951)
Controls	Yes	Yes	Yes	Yes
N	25	25	25	24

Robust standard errors in parentheses

$^{+}$ $p < 0.20$, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table: Column 1 and 3 share of pupils in the total population. Column 2 and 4 municipal and cantonal spending per pupil.

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Political demand education

Effect early electricity adoption on support for education demands

Dependent Variable: Pro-votes in Swiss referendums on education						
	(1)	(2)	(3)	(4)	(5)	(6)
	1902	1963	1964	1973	1973	1978
Change electricity 1880-1900	0.940^{+}	0.168^{+}	0.483^{***}	1.790^{***}	1.256^{***}	1.171^{***}
	(0.667)	(0.117)	(0.131)	(0.674)	(0.304)	(0.274)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
adj. R^2	0.218	0.544	0.507	0.173	0.429	0.208
N	178	178	178	178	178	178

Robust standard errors in parentheses are clustered at the cantonal level

$^{+}$ $p < 0.20$, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Share of votes in favour of central government education and research spending.

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Vocational education

Effect early electricity adoption on vocational education

Dependent Variable: Change in dual education institutions 1880-1910

	All	Polytechnic	Vocational
	(1)	(2)	(3)
Panel A. All districts			
Change electricity 1880-1900	1.199	1.041^{+}	0.158
	(1.332)	(0.771)	(0.723)
N	178	178	178
Panel B. Cantons			
Change electricity 1880-1900	42.662**	14.682***	27.980^{+}
	(17.823)	(3.070)	(17.256)
N	25	25	25
Panel C. Population centres			
Change electricity 1880-1900	17.319**	9.564**	7.756
	(8.632)	(4.037)	(6.504)
N	63	63	63
Panel D. Students in 1910			
Change electricity 1880-1900	5737.043**	392.076	5344.967**
	(2450.812)	(1654.997)	(2458.889)
N	63	63	63
All specifications:			
Controls	Yes	Yes	Yes

$^{+}$ $p < 0.20$, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

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Innovation

Effect early electricity adoption on patenting

Dependent Variable: Patents per person	(1)	(2)	(3)	(4)
	All patents	City	Town	Rural
Change electricity 1880-1900	0.111***	0.003	0.042**	0.066**
	(0.033)	(0.009)	(0.020)	(0.029)
Controls	Yes	Yes	Yes	Yes
adj. R^2	0.225	0.266	0.071	0.122
N	178	178	178	178

Robust standard errors in parentheses are clustered at the cantonal level

$^{+}$ $p < 0.20$, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Number of patents registered (1980-2017) per person.

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Infrastructure network

Effect early electricity adoption on infrastructure network

Dependent Variable: Measures of infrastructure			
	(1)	(2)	(3)
	Operation Points (km^2)	Tunnels (km^2)	Passengers ($pp.$)
Change electricity 1880-1900	0.262^{*}	0.056^{*}	3.762^{***}
	(0.151)	(0.030)	(1.253)
Controls	Yes	Yes	Yes
adj. R^2	0.632	0.429	0.130
N	178	178	178

Robust standard errors in parentheses are clustered at the cantonal level

$^{+}$ $p < 0.20$, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Swiss railway operation points on line as of 2020, tunnels as of 2019, passenger numbers as recorded at train stations in 2018.

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Political demands: Infrastructure and taxation

Effect early electricity adoption on demand for infrastructure

Dependent Variable: Pro-votes in Swiss referendums						
Panel A. Infrastructure						
	1877	1891	1897	1927	1945	1987
Change electricity 1880-1900	-0.696	-0.608	0.091	0.483*	1.178***	1.699***
	(0.605)	(0.547)	(0.703)	(0.265)	(0.361)	(0.411)
Panel B. Taxation						
	1885	1917	1918	1922	1923	1930
Change electricity 1880-1900	-0.902	0.640	1.027**	0.537***	0.601+	0.839***
	(0.747)	(0.606)	(0.493)	(0.179)	(0.369)	(0.323)

Robust standard errors in parentheses are clustered at the cantonal level
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Share of votes in favour of infrastructure spending and taxation.

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Geographical Distribution

Dependent Variable: Share employment 2011

Panel A. Potential water-power

	(1) Agriculture	(2) Manufacturing	(3) Services
Log potential waterpower (1km)	-0.017***	0.004***	0.013***
	(0.000)	(0.000)	(0.000)
Log potential waterpower (1-5km)	-0.014***	-0.000	0.014***
	(0.000)	(0.000)	(0.000)
Log potential waterpower (5-10km)	0.003***	0.000	-0.003***
	(0.000)	(0.000)	(0.000)
adj. R^2	0.026	0.001	0.016
N	206359	206359	206359
District FE	No	No	No

Panel B. Potential water-power with District FE

	(1) Agriculture	(2) Manufacturing	(3) Services
Log potential waterpower (1km)	-0.018***	0.005***	0.013***
	(0.000)	(0.000)	(0.000)
Log potential waterpower (1-5km)	-0.013***	0.002***	0.011***
	(0.000)	(0.000)	(0.000)
Log potential waterpower (5-10km)	0.001**	0.001**	-0.002***
	(0.001)	(0.000)	(0.001)
adj. R^2	0.126	0.009	0.098
N	206359	206359	206359
District FE	Yes	Yes	Yes

Robust standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

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Power-stations

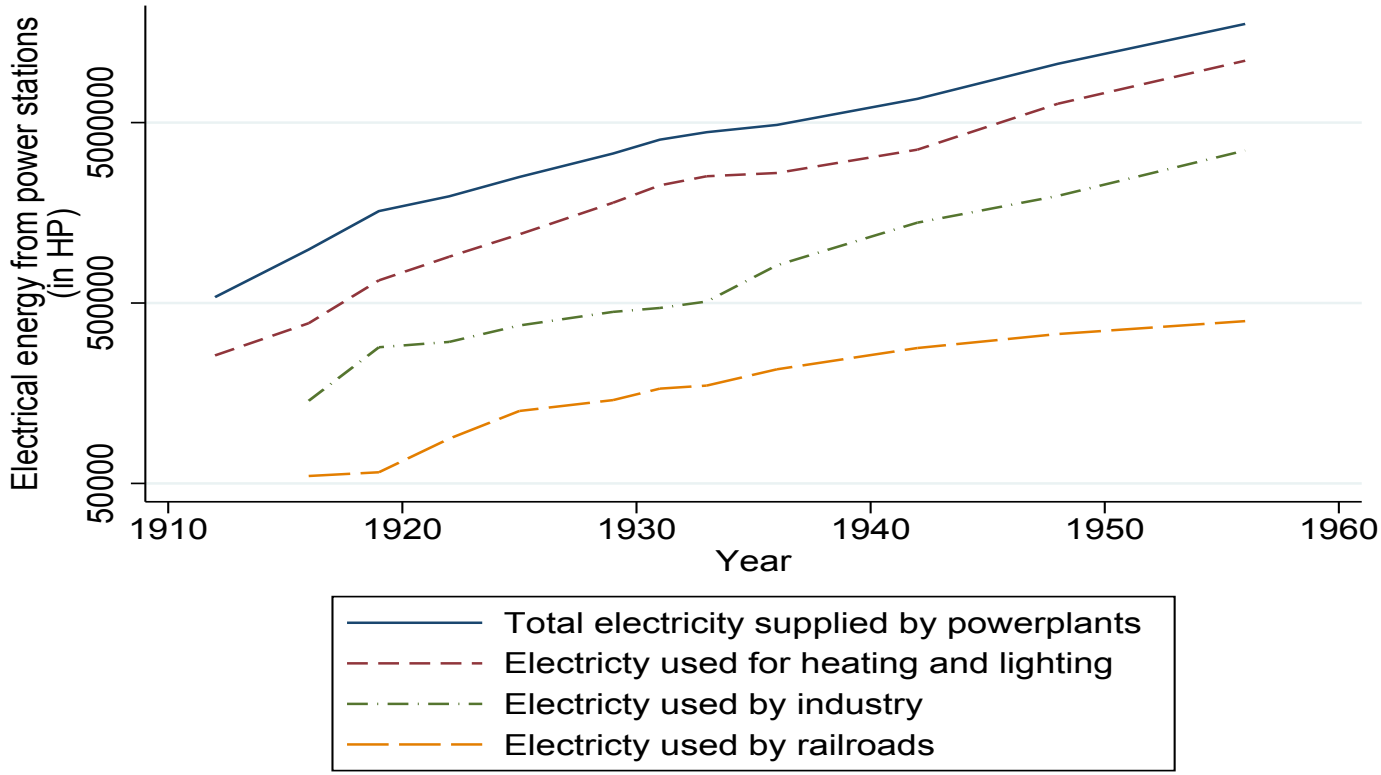

Figure: Electricity produced by power stations for general supply in log Megawatt from 1912 to 1956 and the share of general electricity produced provided to industry and railroads. Source: Historical Statistics of Switzerland.

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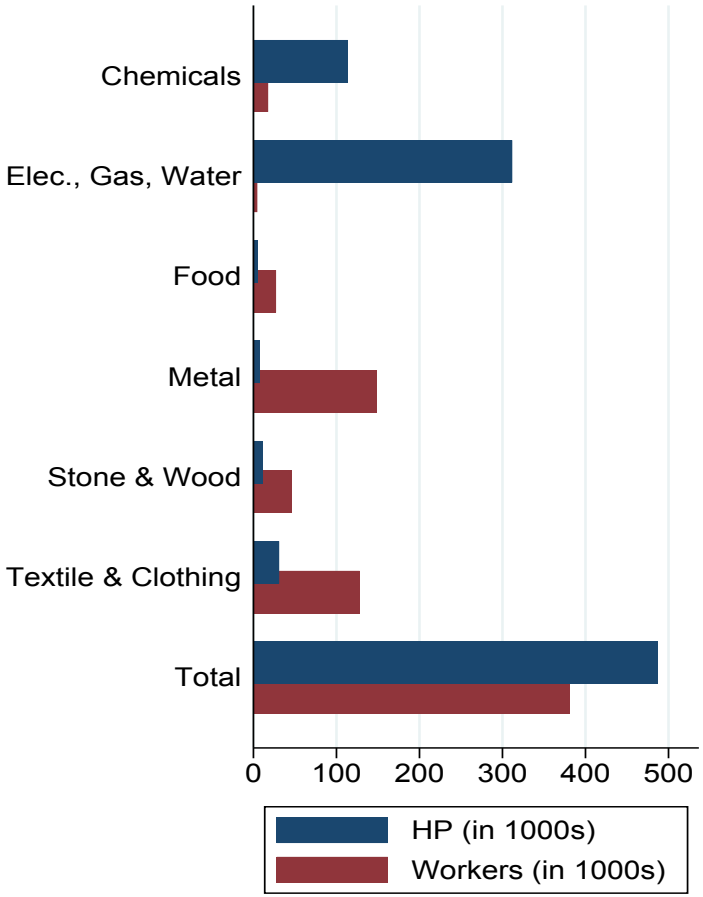
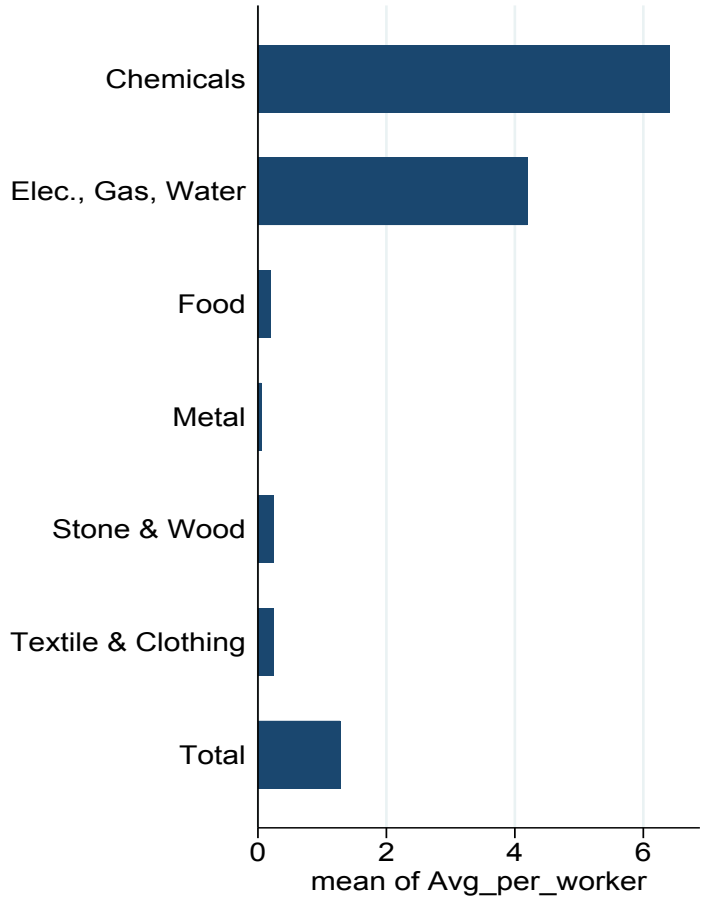
Energy intensity





Usage of waterpower and employment in 1918 by industry categories. Source: Statistical Yearbook 1918.

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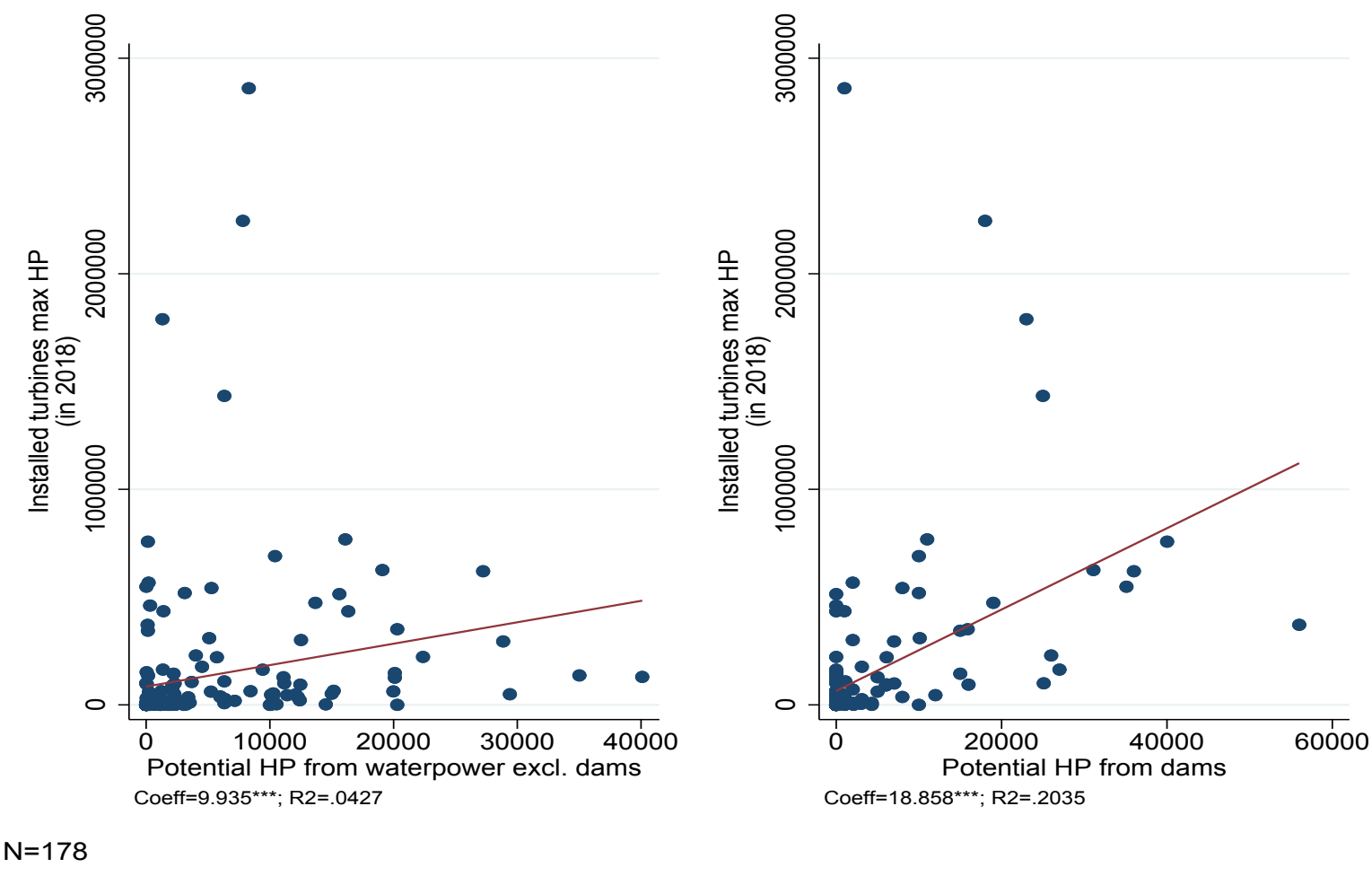
Current production water-power



The relationship between maximum potential power production of installed turbines in 2018 and the waterpower potentital.

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Migration

Effect of access to electricity on migration

Dependent Variable: Change in share of locals and migrants

	(1) Municipality	(2) Canton	(3) Swiss	(4) Foreign
Change electricity 1880-1900	-0.103	-0.126^{+}	-0.027	0.257^{+}
	(0.193)	(0.095)	(0.045)	(0.171)
Controls	Yes	Yes	Yes	Yes
N	178	178	178	178

Robust standard errors in parentheses are clustered at the cantonal level

$^{+}$ $p < 0.20$, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Change share of population born in municipality of residence, same canton, in Switzerland, and abroad 1880-1900.

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