The Research University, Invention, and Industry
Evidence from German History

Jeremiah Dittmar and Ralf R. Meisenzahl

LSE and Chicago FED

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Can universities drive major changes in industrial activity?

Debate on role of universities

- Limited role in British Industrial Revolution, but may offer 'cure for technological backwardness' — Landes (1969)

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German history as example and model

- Germany develops *research university*, industrializes in 1800s
- Challenge: pre-1840 econometric '*terra incognita*' – Tilly

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Our contribution

- French Revolution delivers pro-science shock in Germany
- New evidence — on invention and manufacturing 1760-1900 that (i) cover longer time and (ii) are spatially disaggregated
  - Universities not historical centers of technology or industry
  - Shift in early 1800s, especially in knowledge intensive industries
  - University predicts adoption of, internat'l prizes for, innovation

Long-Run Prosperity — the German Path

Social revolutions have spillovers across borders

- 'social revolutions have given rise to models and ideals of enormous international impact and appeal. . . '
  — Theda Skocpol, *States and Social Revolution* (1979)

The German path — a major and important example

- a high knowledge production path to capitalist modernity without democracy — no bourgeois revolution, instead a 'revolution of the mind' plus reactionary politics

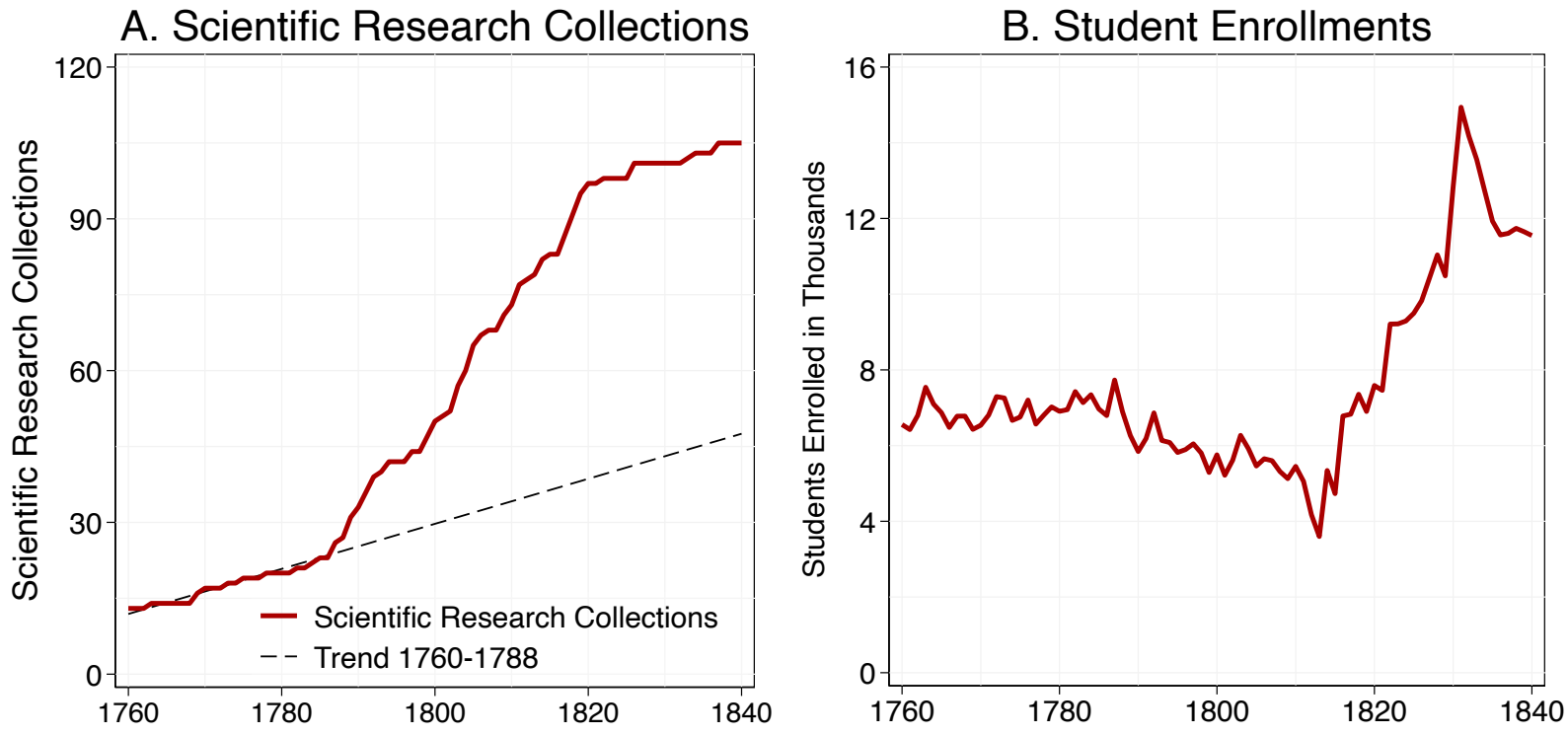
  (Blackbourn & Eley, R.R. Palmer, Engels...)

Conceptual Innovations in University Education

"This early 19th century concept of *wissenschaftliche Bildung* (scientific education) had a profound impact on the history of the German university. . . Setting themselves the task to represent the 'unity of science'. . . they were reconceptualised as the pre-eminent loci of research and *Bildung* (education)."

– Van Bommel (2015)

University Research Collections and Enrollments



The *scientific research collections* are the number of university collections in: physics, chemistry, minerals, technology, and the botanical and life sciences

(these notably support training of mechanics, technologists *outside* university)

Preview: Inventions and Scientific Discoveries

Compare Towns Above and Below Median Distance to University

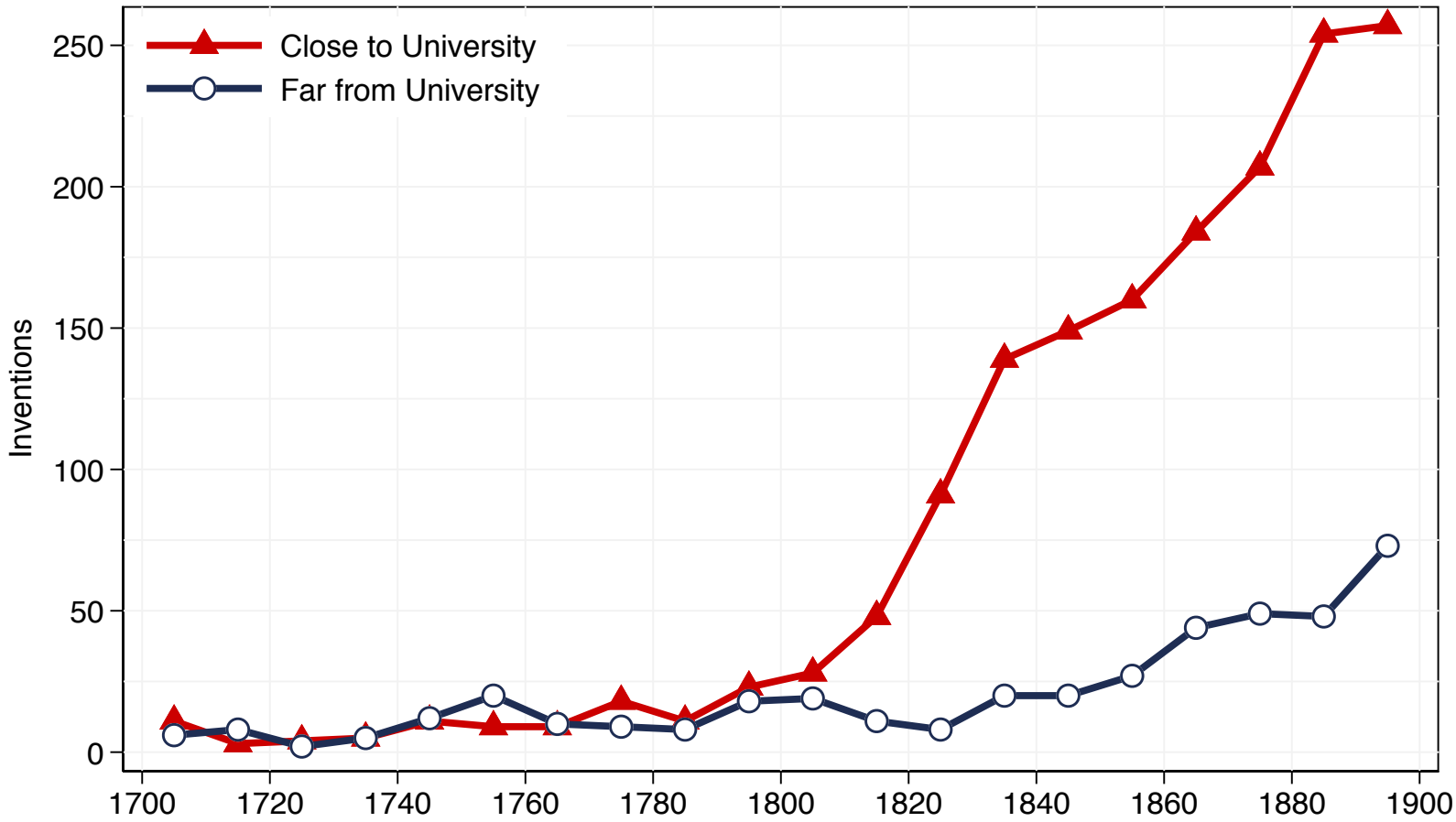


Figure: Major Inventions and Scientific Discoveries

History of tech: geocode observations in *Handbuch zur Geschichte der Naturwissenschaften und der Technik*

Preview: Manufacturing – Plant Openings 1800-1859

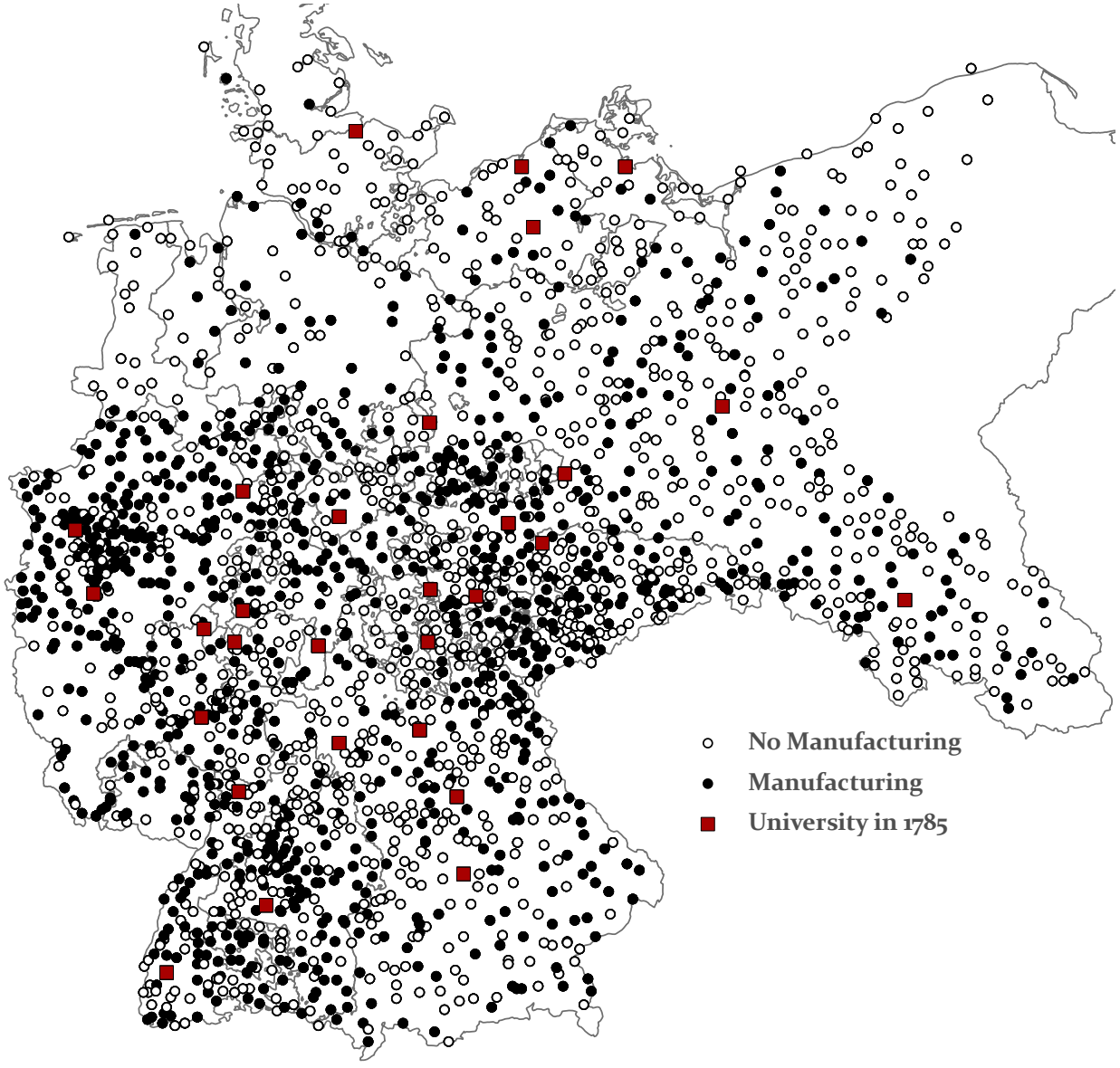


Figure: Manufacturing activity of towns in the *Deutsches Städtebuch*

Preview: Proximity to Universities and New Manufacturing

	Any New Manufacturing Mean Across Towns		Count New Manufacturing Sum Across Towns	
Time Period	Close to University	Far from University	Close to University	Far from University
1760-1799	0.12	0.13	179	188
1800-1859	0.67	0.50	1445	970
1860-1899	0.63	0.61	1023	979

- Compares towns below and above median distance to a university as of the 1780s. Number of towns: 2,254 (1,127 close and 1,127 far)
- Median distance cut off $\approx$ 60 kilometers
- Period 1: before shock. Period 2: after. Period 3: fall in price of transport

How did Germany become a leading industrial economy?

Canonical story: railroad, heavy industry, banking, chemicals

- *Mid-1800s growth spurt* — railroads, metal industries
  (Gerschenkron 1962, Fremdling 1977, Pierenkemper &Tilly 2004)

The canonical story is of course debated

- *Continuous process* — prior development, railroad induced
  (Ogilvie 1999, Kaufhold 1981, Kopsidis & Bromley 2017)
- *Other factors matter post-1850* — education, institutions
  (Landes 1969, Acemoglu et al. 2011, Becker et al. 2014)
- *Early 1800s shift* — industrialization with reactionary politics
  (Kuczynski 1961, Forberger 1958, Wehler 1987)

Our analysis – new, disaggregated evidence

Invention and science — patented and non-patented ideas

- Data from history of tech before advent of patent systems

Manufacturing and innovation

- Plant openings — from encyclopaedia of German towns
- Technology adoption — mechanization at factory level
- Prizes for innovations — at first World's Fair in 1851

High level — where do we look for economics of innovation?

- Schmookler 1966, Moser 2004, MacLeod & Nuvolari 2016
- Compare to patterns of 'democratic invention' in the USA?

Hypotheses

1. **Location of industry.** We expect to find industrial activity increasing around universities after circa 1800
2. **Knowledge intensive industry.** We expect the university effect will be concentrated in knowledge intensive sectors
3. **Technological change.** We expect technological change to concentrate near universities — mechanization is cutting edge
4. **The quality of innovation.** We expect high quality innovation to cluster near universities — as evidenced by competitive, international prizes for industrial innovation

Hypothesis 1: The Location of Industrial Activity

The *Deutsches Städtebuch* records industrial history of towns

We code *plant openings* 1760-1900 across 2,254 towns

Our measure predicts number of workers and number of factories at the county-by-sector level in 1849 Prussian Census

Town	Year	Manufacturing Activity	Sector
Schwabach	1801	Buchdruckerei	Printing
Mannheim	1801	Machinenfabrik	Industrial Machinery
Allersberg	1801	Drahtfabrik	Fabricated Metal
Bad Neustadt	1801	Getreidemühle	Food Processing
Hoehr-Grenzhausen	1801	Papiermühle	Paper
Euskirchen	1801	Tuchweberei	Textiles
...	...	...	...
Chemnitz	1843	Lokomotivenbau	Transport Equipment

Table: Examples in the data

What is the Variation We Investigate?

Manufacturing in towns 'close' or 'far' to universities

- Finding: shift toward universities and increase in early 1800s
- Counterfactuals: all variation and *within* territory-x-year cells — thus within 44 territories that constitute historic 'Germany'

Was the location of universities exogenous?

- Preindustrial foundations, in small towns, non-scientific aims and 'could not be shifted' – Segal (2018)
- But note new universities: Berlin 1810, Munich 1826

What about other factors shifting across time and space?

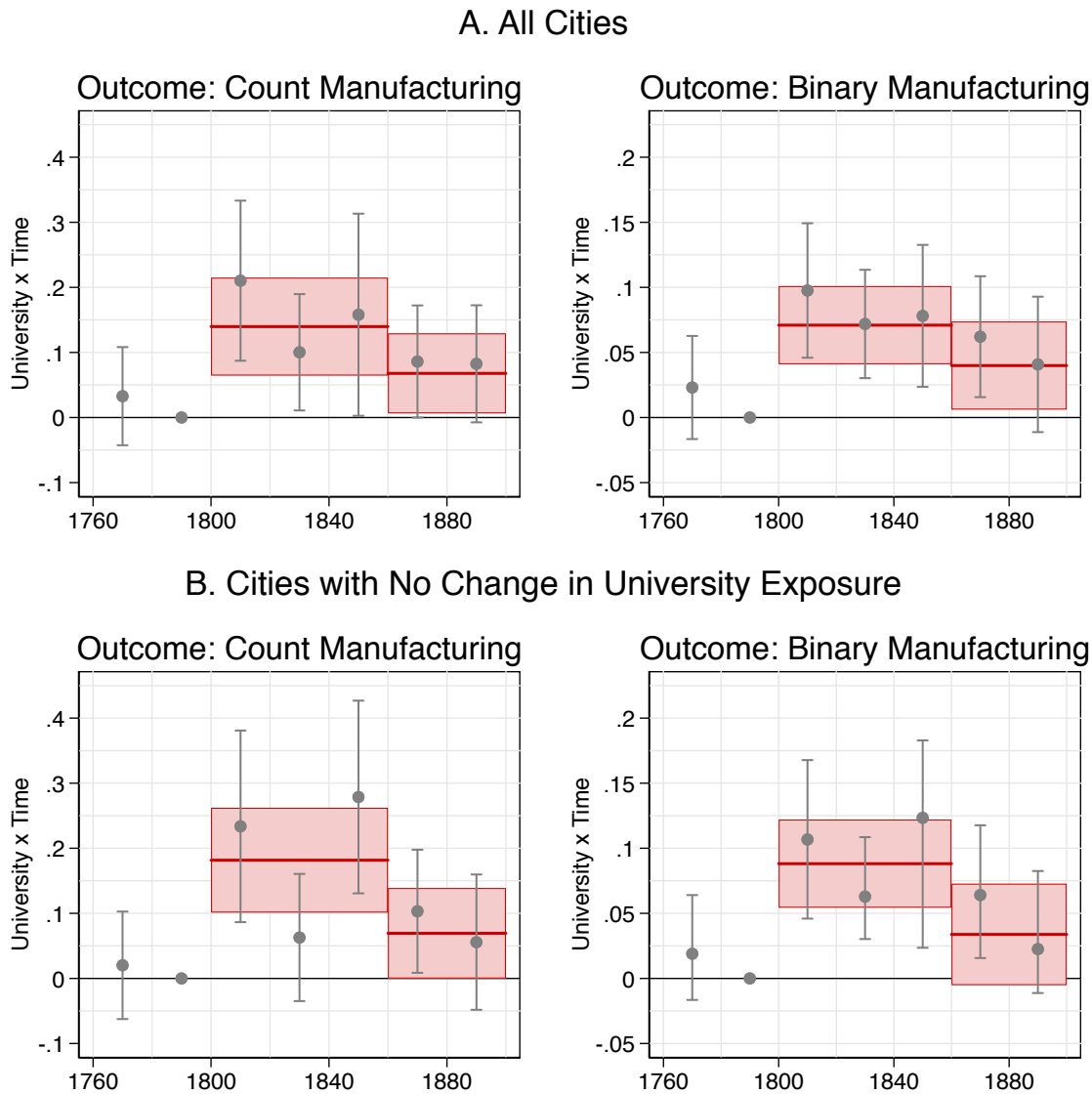
- Railroads? Regional institutions? Customs union? Schools?

Research Design

$$manufacturing_{it} = \sum_{s} \beta_s (university_i \times time_s) + \theta_i + \delta_t + \gamma X_{it} + \epsilon_{it}$$

- Outcome — plant openings as count or indicator by town-time
- University exposure — measured by below median distance, also linearly and flexibly in distance
- Cause and effect — the exogeneity of location
  - Study university exposure for all towns, using university locations in 1800s, a few of which potentially endogenous
  - Restrict to cities those whose university exposure does not shift due to potentially endogenous university locations
- Inference — spatial standard errors

Baseline — University Proximity and Manufacturing



- Panel A: All cities: $n = 2,254$. Panel B: No change in exposure: $n = 1,686$
- Graph shows: (i) flexible estimates and (ii) estimates assuming two post periods

Interpretive Questions

- **Regions.** Institutional change due to Napoleon in the West?
- **Other changes.** Prussian reforms? Local development of schooling at lower levels? Railroads? Tariff barriers?
- **Where is the variation?** Does the effect hold within regions?

Universities and Other Factors

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Outcome: Count of Manufacturing Events						Outcome: Binary	
	In All Industries				In New Industries		In All Industries	
	1760-1899	1760-1839	1760-1839	1760-1839	1760-1839	1760-1839	1760-1839	1760-1839
University × 1800-1859	0.14***	0.13***	0.13***	0.07**	0.12***	0.06**	0.07***	0.05***
	(0.04)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.01)	(0.01)
University × 1860-1899	0.06**							
	(0.03)							
Free Enterprise Law	0.10***	0.07*	0.07*		0.07*		0.01	
	(0.03)	(0.04)	(0.04)		(0.04)		(0.01)	
Early Manufactures × Post-1800	0.15***	0.20***	0.20***	0.18**	0.11**	0.09	0.04	0.03
	(0.05)	(0.07)	(0.07)	(0.07)	(0.06)	(0.06)	(0.02)	(0.02)
Coal × Post-1800	-0.03	-0.02	-0.02	-0.08*	-0.01	-0.08*	0.03**	-0.00
	(0.04)	(0.04)	(0.04)	(0.05)	(0.03)	(0.04)	(0.01)	(0.02)
Coal × Post-1840	0.13***							
	(0.05)							
Railroad Connection	0.24***							
	(0.06)							
Higher School	0.18***	0.20***	0.11	0.11	0.08	0.09	0.05*	0.04
	(0.04)	(0.07)	(0.09)	(0.09)	(0.08)	(0.08)	(0.03)	(0.03)
Higher School: Lead			0.14**	0.13**	0.13**	0.12**	0.05**	0.05**
			(0.07)	(0.07)	(0.06)	(0.06)	(0.02)	(0.02)
Higher School: Lag			0.09	0.09	0.10	0.09	0.02	0.02
			(0.10)	(0.10)	(0.09)	(0.09)	(0.04)	(0.04)
City FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	No	Yes	No	Yes	No
Territory-×-Time FE	No	No	No	Yes	No	Yes	No	Yes
Observations	15778	9016	9016	9016	9016	9016	9016	9016
Mean Outcome	0.27	0.19	0.19	0.19	0.17	0.17	0.12	0.12

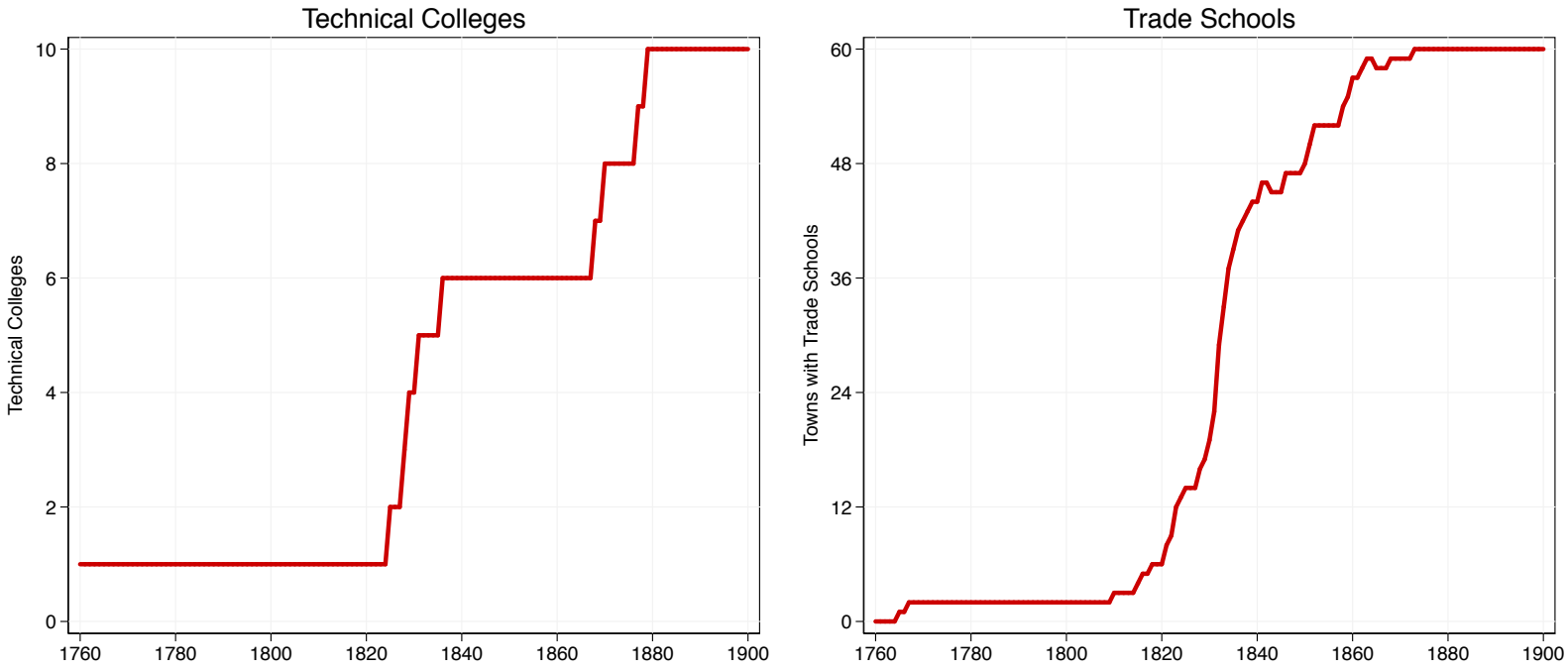
— Unit of observation is a town-period: 2254 towns, 20-year time periods, 1760 to 1899
— 'New' manufacturing defined at town-level: two-digit industry in which town had no activity before 1760
— within 'territory' variation: Principality of Brunswick: 9 close, 9 far; Province of Saxony: 91 close, 63 far

Larger Universities Drive These Effects

	(1)	(2)	(3)
	Outcome: Manufacturing Events		
	All Cities	Exclude Cities Near Berlin or Munich	
	Baseline	Baseline	Large v. Small
University x 1800-1859	0.14***	0.13***	
	(0.04)	(0.04)	
University x 1860-1899	0.07**	0.06	
	(0.03)	(0.04)	
Large University x 1800-1859			0.16***
			(0.05)
Small University x 1800-1859			0.07
			(0.05)
Large University x 1860-1899			0.14***
			(0.05)
Small University x 1860-1899			-0.08**
			(0.04)
City FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
Observations	15778	11361	11361
p-value: Large = Small 1800-1859			0.10
p-value: Large = Small 1860-1899			0.00

'Large' are above median enrollment (top 7). 'Small' are below (bottom 8).

Other Changes in Education Come Later & Elsewhere



- **Technical colleges** — *Technische Hochschulen* — not in university towns, with exception of Munich (est. 1868) and Berlin (est. 1879)
- **Trade schools** — *Gewerbeschulen* — most in cities without universities

Hypothesis 2: Knowledge Intensive Manufacturing

Question — 'Was university exposure in fact associated with shifts in more knowledge-intensive industries?'

- We define as 'knowledge intensive' industries — those using inventions by relatively more university-educated inventors

Evidence on Invention

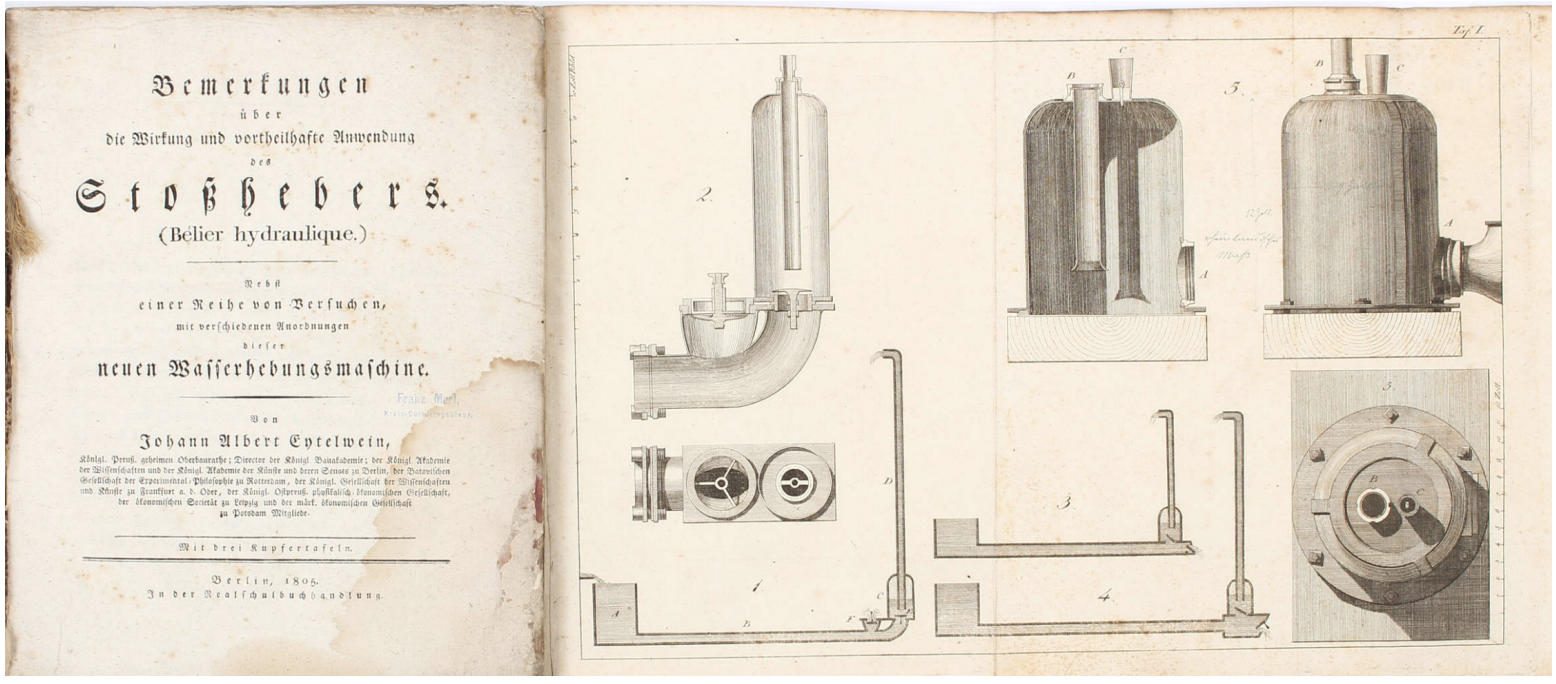
Catalogue of major inventions and discoveries

- Darmstädter et al.'s *Handbuch zur Geschichte der Naturwissenschaften und der Technik* (1908)
- 60+ contributors including multiple Nobel Laureates
- Describes contributions, identifies inventors

We gather our own data on location, education, employment

- We research individual biographies in *Allgemeine Deutsche Biographie*, *Neue Deutsche Biographie*, historical sources...

Example of an invention in our data



Bemerkungen
über
die Wirkung und vortheilhafte Anwendung
des
Stoßhebers.
(Bélier hydraulique.)

Nebst
einer Reihe von Versuchen,
mit verschiedenen Anordnungen
dieser
neuen Wasserhebungsmaschine.

Von
Johann Albert Eytelwein,

Mit drei Kupfertafeln.

Berlin, 1805.
In der Realschulbuchhandlung.

Figure: Hydraulic lift invented 1805 by Johann Albert Eytelwein

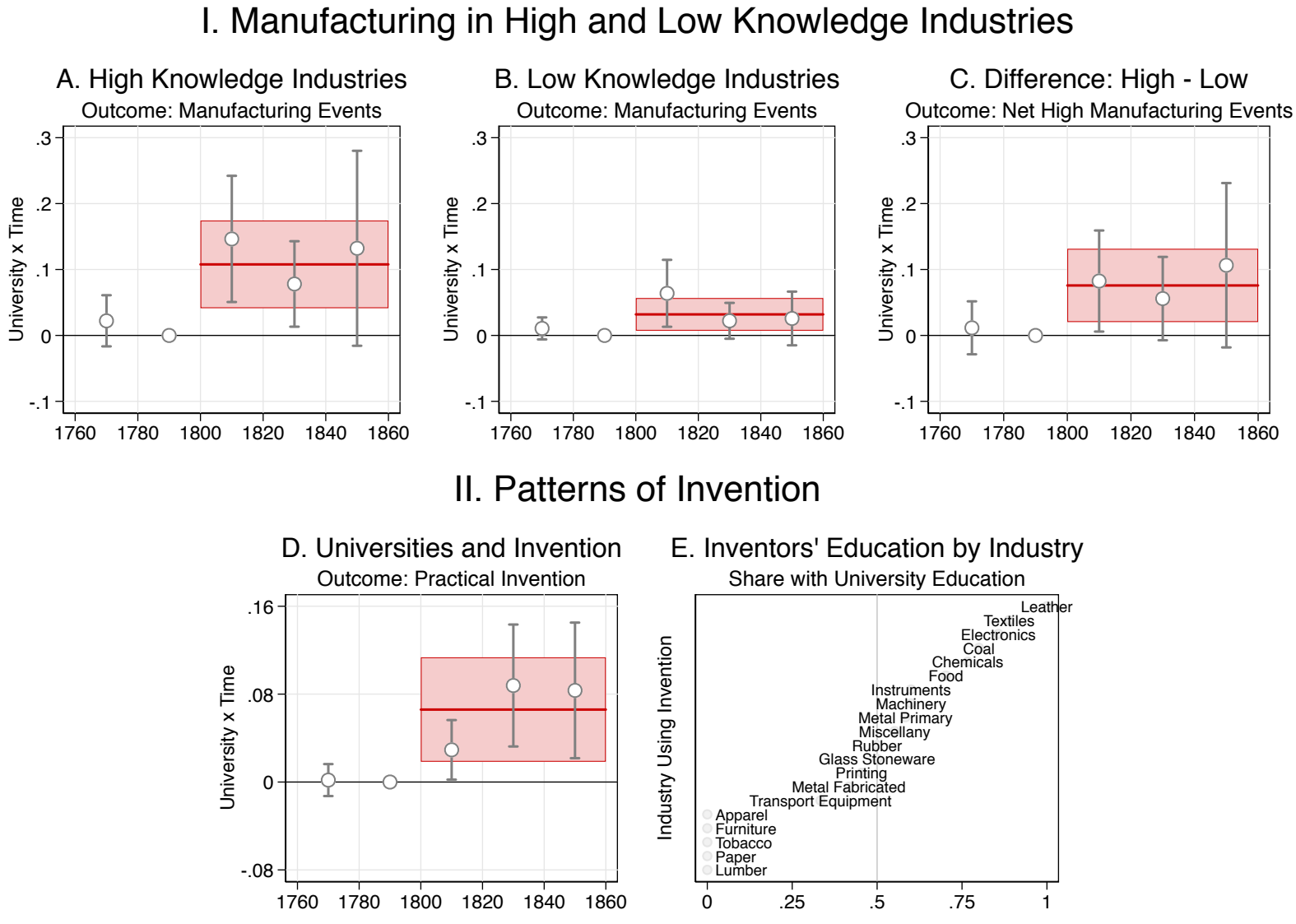
Inventions — Location, Industry, & Inventors' Education

Subject	Translation	Year	Town	Industry	University
Registrierapparate, selbsttätige	Automatic register apparatus	1805	Berlin	Equipment	1
Spannungsreihe der Metalle	Metal stress tests	1808	Halle	Metals	1
Glycirrhizin	Glycyrrhizic acid	1808	Kiel	Chemicals	1
Stahl- und Flus-seisenbereitung	Steel and cast iron production	1811	Essen	Metals	0
Silbersalze	Silver salts	1811	Bayreuth	Chemicals	1

Table: Example of several observations we hand-code

Universities and Knowledge Intensive Manufacturing

Compare Towns Above and Below Median Distance to University



Hypothesis 3: Technological Change

- Evidence so far does not indicate the *technology* actually used
- Examine firm-level evidence from Germany's leading industrial region, Saxony
- Measure technology with mechanization of production
  - Mechanized factory – 'cotton machine spinning' (*Baumwollmaschinespinnerei*)
  - Non-Mechanized factory – 'cotton spinning' (*Baumwollspinnerei*)
- Compare firms in cities closer to and further from university

Universities and Technological Change

Mechanization in Factories 1800-1830

	(1)	(2)	(3)	(4)
	Number of Firms Mechanized		Number of Firms Not Mechanized	
University	1.90***	1.50***	0.55	0.43
	(0.64)	(0.56)	(0.66)	(0.64)
Lags of Manufacturing		Yes		Yes
Observations	164	164	164	164
Mean	1.17	1.17	0.25	0.25

Table: The mechanization of factories in Saxony

— Outcome: mechanized firms in a city 1800-1830, "first phase of the Industrial Revolution" (Forberger 1982)
— Poisson regression cols 1-4, OLS cols 5-6
— Control for appearance of non-mechanized firms in prior periods, data on firms in 164 towns

Hypothesis 4: The Quality of Innovation

Were universities associated with innovations that took German industry towards or pushed out the world technology frontier?

- Examine data on exhibits and prizes at first world's fair — Crystal Palace 1851, following Moser (2005)
- Punchline
  - Cities near universities look like Belgium
  - Cities far from universities look like Spain
  - Cities below median distance to university...
    - 58% of total exhibits from our study area
    - 69% of high quality — award-winning — exhibits

The Quality of Industrial Innovation

University Exposure and Prizes at the First World's Fair

	(1)	(2)	(3)	(4)	(5)	(6)
	Outcome: Number of Exhibits from a City					
	Total	Low	High	High Quality By Type		
	Exhibits	Quality	Quality	Materials	Machines	Manufactures
University	0.34*	0.14	0.82**	1.03***	1.54***	0.65*
	(0.19)	(0.14)	(0.37)	(0.31)	(0.31)	(0.35)
Observations	2254	2254	2254	2254	2254	2254

— Outcome: number of exhibits of given type

— Poisson regression model

Larger Take-Aways

1. Canonical example of role of higher education in catch-up growth and in changing in knowledge production
   - Indicates universities *not* transhistorically good for growth
   - Invites us to reconsider definition of 'science' in economics

2. Shift to industrialization occurs earlier and differently than often assumed – in the early 1800s and around universities
   - Evidence on timing consistent with East German research

3. Sequence of political and cultural changes indicates importance of larger social processes for growth
   - Equally German experience with war and Fascism in 20th century indicates potential fragility of science-based growth