

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

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Abstract

We examine the role of universities in knowledge production and industrial change using historical evidence. Political shocks drove a profound pro-science shift in German universities in the late 1700s. To study the consequences, we construct novel microdata. We find invention and manufacturing developed similarly in cities closer to and farther from universities in the 1700s and shifted towards universities and accelerated in the early 1800s. The shift in manufacturing was strongest in new and high knowledge industries and near large universities. After 1800, the adoption of mechanized technology and the number of firms winning international awards for innovation were higher near universities.

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One might define modern economic growth as the spread of a system of production, in the widest sense of the term, based upon the increased application of science. . .

– *Kuznets (1968), Reflections on the Economic Growth of Modern Nations*

1 Introduction

Can universities drive major changes in industrial activity? The pre-modern university focused on non-scientific knowledge and did not drive industrial activity. In contrast, the modern research university, which first developed in early 19th century Germany, is a unique producer of scientific knowledge and human capital, which are essential for modern growth. Yet surprisingly little economic research documents whether and how the modern research university promotes long-run growth and large scale transformations of the economy.

In this paper, we document that research universities were instrumental in shifting the German economy from a position of backwardness onto a path to the world frontier in technology and industry. We assemble novel data on the development of technology and manufacturing plants across German cities from 1760 to 1900, and study how changes in research universities induced modern growth, using within-Germany variation. Our analysis finds that the effects of modern universities precede and dominate factors emphasized in prior research, and rests on the first large-scale panel microdata covering the development of industrial activity and technology across Germany before the 1840s, so far as we are aware. We show that universities drove a take-off in invention and industry in neighboring cities before railroads appeared and controlling for differences in regional institutions. The effects we document are not driven by endogenous university locations. We find that historic universities, whose locations were fixed and which did not previously drive economic activity, became modern research universities and subsequently drove industrialization.

We document how universities shaped a major pivot in the development of invention and industrial activity in the early 1800s by investigating novel, disaggregated data from Germany.¹ We first show that universities sharply increased their investments supporting scientific research starting in the 1790s. We then show that levels and trends in scientific and technological discovery were similar in cities near to and far from universities before

¹We use “Germany” and “German” as short-hands. We analyse economic activity in 2,254 historically German-speaking cities that were in the Holy Roman Empire before 1805, the German Union (*Deutscher Bund*) after 1805, and the German Empire after 1871 and before WWI.

1800, and shifted significantly towards universities after 1800. We next study evidence on manufacturing plants at the city and city-by-sector level. We document that manufacturing developed similarly in cities nearer to and farther from universities in the 1700s, and shifted towards universities and accelerated in the early 1800s. The increase in manufacturing around universities was concentrated in new and knowledge intensive industries. In addition, we find that firms in cities near universities were more likely to adopt mechanized production technologies and to win international prizes for industrial innovation.

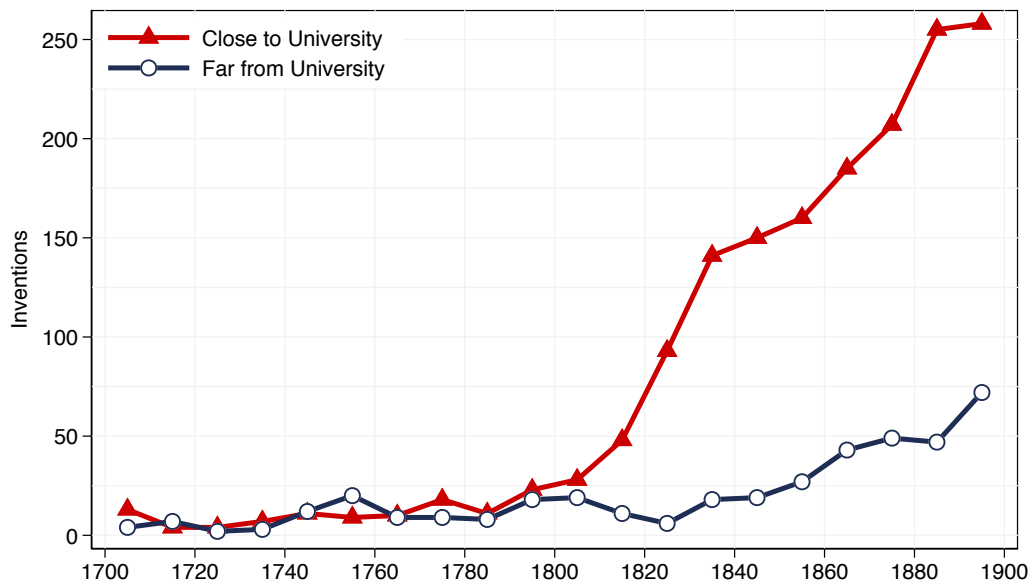
Exogenous political shocks drove the changes in universities whose consequences we study. The French Revolution (1789) famously led to the development of a ground-breaking, pro-science and pro-research model for university education in Germany (Palmer 2014; Blackburn 2003; Rüegg 2004a; McClelland 2008; Van Bommel 2015). McClelland (2019; p. 6) observes, “the inertia of most of the traditional faculties could not be broken until the increasingly powerful waves of change emanating from France after 1789 placed the ‘German university’ before a potential inundation.” The number of scientific research collections at German universities doubled after the French Revolution and before the Napoleonic invasion of 1805, leaping off prior trends (Section 2.2). Scientific and technical activities at universities expanded, including mechanical institutes designed to promote spillovers into local industries (Ziche 2001).² By the mid-1800s, the excellence of German universities and their superiority in the sciences were recognized internationally.³ Before the French Revolution, German universities focused on theology and law and enrollments were stagnant (Turner 1975).

Economic theory predicts that geographic shifts in knowledge production will generate spillovers that transform the nature and location of industrial activity (Marshall 1920; Audretsch and Feldman 1996). We motivate our study of changes in industrial activity with a new stylized fact: scientific and technological discovery increased and shifted spatially towards universities in early 1800s Germany, as shown in Figure 1. This evidence and economic theory lead us to test four hypotheses. First, we expect to find industrial activity increasing around universities. For this relationship to be causal, it should hold where university locations were pre-determined and had not previously conferred economic

²We distinguish the effects of universities from other institutional and economic changes precipitated by the French Revolution, which varied across regions and cities in a different manner, as detailed below.

³In other countries, the research university was adopted endogenously in the later 1800s in response to developments observed in and around universities in Germany (Arnold 1868; Urquiola 2020).

Figure 1: The Pattern of Scientific and Technological Discovery



This graph plots data on major scientific and technological discoveries from [Darmstaedter, du Bois-Reymond, and Schaefer \(1908\)](#), located across 2,254 German cities recorded in [Keyser \(1939-1974\)](#). Cities “Close to University” and “Far from University” are those below or above median distance in a given decade.

advantage. Further, if research universities supplied new and economically useful knowledge and human capital, we would expect larger universities to have larger spillover effects and for cities near universities to differentially expand “new manufacturing,” in industries previously not present. Second, we expect that these increases in industrial activity will also be concentrated in knowledge intensive sectors. Third, we expect that technological change will increase most around universities. Fourth, we expect to find universities are associated with high quality industrial innovation after 1800.

We first test whether industrial activity increased around universities after 1800. We use distance to university to measure the spillover effects of universities on manufacturing. We find that cities near universities enjoyed no advantage or differential positive trend in manufacturing in the 1700s, and that manufacturing expanded significantly in cities near universities in the early 1800s, confirming our first hypothesis. Our analysis rests on novel evidence on the establishment of manufacturing plants across every city in historic Germany from 1760 through 1899, which covers periods before census data are available.⁴

We address questions about identification with several analyses, which all support a

⁴We collect data on manufacturing activity (establishments) at the city-industry-time level as recorded in the *Deutsches Städtebuch*, an encyclopedia of 2,000+ historic cities. Our data strongly predict the number of factories and number of workers in two-digit industrial sectors when census coverage begins in the mid-1800s.

causal interpretation of the relationship between research universities and manufacturing. A first question is whether our findings may be driven by potentially endogenous university locations. However, there are no pre-trends towards universities, and the positive shift in the relationship between universities and manufacturing after 1800 is not driven by new universities or changes in locations. A second question is whether underlying regional factors could account for the university effect. However, when we compare cities within the same political territory, and control for time-varying factors shared by all cities in a territory, we find universities still strongly promoted manufacturing after 1800. The university effect is thus not explained by regional factors, including otherwise important institutional changes after the French Revolution. A third question is whether the university effect could be explained by others factors that vary across cities *within* regions and over time, in particular the development of schooling at other levels. However, we collect detailed evidence on all schools in the cities we study and find schooling is neither a confounder nor itself a driver of manufacturing in our period. A fourth question is whether other major economic changes could explain the shift in industrial activity around universities. However, we observe the effect of universities on industry starting in the early 1800s, decades before the German customs union lowered trade barriers, railroads appeared, coal deposits became important for the location of industry, and the emergence of Germany’s distinctive universal banks.

We next test mechanisms driving our main result. If universities drove industrialization, we would expect larger universities to generate larger effects, whereas a general spread of science would not be related to university sizes. In the data, we find the university effect on industrial activity concentrated in cities near larger universities. In addition, if research universities shifted the supply of human capital and new useful knowledge, as the history suggests, we would expect universities to be particularly important for the development of new industrial activities. We test and confirm that after 1800 cities near universities differentially developed new industries which did not previously exist in a given city.

We extend our analysis to test whether the university effect was concentrated in knowledge-intensive industries, as our second hypothesis suggests. To measure the knowledge intensity of industries, we use our data on technological discovery, in which we gather evidence on inventors’ educations. We classify industries as “high knowledge” and “low knowledge” based on the share of inventions used in a given two digit SIC industry made by

university-educated inventors. We find that the shift in manufacturing towards universities was largely driven by high knowledge manufacturing, consistent with our hypothesis.

To test our third hypothesis, that universities promoted technological change, we examine establishment-level evidence on the adoption of mechanized production technology. Our principal source of data, the *Deutsches Städtebuch*, does not record the technology used in different establishments. We therefore construct unique evidence on firm-level mechanization in Saxony, which was the most advanced region of historic manufacturing in Germany. We observe that mechanization increased significantly faster in cities closer to universities in the first decades of the 1800s, consistent with our hypothesis.

Finally, we test whether universities were associated with the *quality* of industrial innovation measured by the development of internationally competitive products and technologies (our fourth hypothesis). We focus on competitive prizes for innovation at the first world's fair, *The Great Exhibition of the Industry of All Nations* at Crystal Palace in 1851 (see Moser 2005). We find that significantly more prizes were won by producers from German cities near universities, consistent with our hypothesis. The share of exhibits winning prizes in German cities near universities was similar to the share winning prizes in Belgium, then the most advanced industrial nation in continental Europe, whereas the share winning prizes in cities far from universities was similar to that in Spain, which was relatively backward. The data from Crystal Palace also provide cross-sectional verification of the patterns in our panel database on science and discovery, shown in Figure 1, but our panel data allow us to trace practical invention increasing within German cities near universities in the early 1800s, consistent with the dynamics in manufacturing.

The increases in industrial activity and invention near universities are likely to reflect how political shocks shifted supply-side and demand-side processes. The pro-science shift at universities increased useful knowledge. However, the patterns that we document are likely to also reflect how political shocks made universities and university-educated inventors more responsive to economic incentives. Indeed, narrative evidence indicates that changes in the late 1700s and early 1800s enabled universities to act in new ways as conduits for induced technological change, for instance through the establishment of mechanical institutes.

Our paper makes several larger contributions to the literature. First, we contribute evidence on the literature on endogenous growth. Economic theory emphasizes the

importance of innovation for growth (Aghion and Howitt 1998; Romer 1994; Nelson and Phelps 1966) and empirical work indicates research universities are potentially key drivers of innovation (Jaffe 1989; Audretsch and Feldman 2004; Foray and Lissoni 2010; Kantor and Whalley 2014; Valero and Reenen 2019). Previous research identifies local spillovers from land grant universities into agricultural productivity over the medium run (Kantor and Whalley 2019) and shows patenting clustered around colleges established during the industrialization process, starting in the mid-1800s in the USA (Andrews 2022). In contrast, we show that the development of the modern research university drove a large-scale acceleration in industrial activity in the early 1800s, and link university invention to the growth of knowledge intensive industries. In prior work, Cantoni and Yuchtman (2014) document that the foundation of universities in Germany in the middle ages led to the establishment of legal institutions that supported the Commercial Revolution of the 1300s and 1400s. However, we find no differences in the level or trend of industrial, inventive, or urban construction activity associated with universities until the development of the modern research university in Germany. We thus provide evidence showing that modern research universities shaped a major pivot in development and that, as Landes (1969, p. 151) observes, scientific education may offer a “cure for technological backwardness.”⁵

We also contribute to the literature on human capital and industrialization. Mokyr (2005) argues that upper tail human capital, produced outside universities, played a central role in British industrialization. Squicciarini and Voigtländer (2015) provide quantitative evidence for this mechanism, showing that fixed city-level differences in upper tail human capital explain the diffusion of the industrial revolution in France. Becker and Woessmann (2009) find that the Protestant Reformation of the 1500s shaped differences in local primary education, which affected economic structure in late 1800s Germany. In contrast, we provide evidence on how political shocks led to the creation of modern research universities and thus increased the supply of upper tail human capital. We show that research universities drove industrialization in Germany starting in the early 1800s.⁶

Our analysis documents how shocks to politics and culture are transmitted into changes

⁵Prior historical studies indicate that universities shaped the development of science in the Renaissance (Dittmar 2019) and the pre-industrial allocation of talent (de la Croix et al. 2022), but made limited direct contributions to innovation and industry in the English Industrial Revolution (Mitch 1999).

⁶We find that primary education become a significant factor in industrialization only in the late 1800s, consistent with Becker and Woessmann (2009).

in the path of growth. Our historical analysis supports [Kuznets’ \(1968; p. 103\)](#) observation that “modern economic development was partly preceded by and partly accompanied by these shifts in the structure of social values, which had an independent existence. . . at critical junctures.” Our quantitative findings reflect how shocks to culture were transmitted through elite education to shape innovation and development, in the spirit of [Mokyr \(2016\)](#). Further, we document the role of the research university in promoting capitalist industrialization in the absence of political liberalization ([Kuczynski 1961; Blackbourn and Eley 1984; Davidson 2012](#)). Indeed, the German path famously involved a “revolution of the mind” but not liberal democracy ([Palmer 2014; Blackbourn 2003](#)).

Lastly, our study also contributes to a classic debate about catch-up industrialization. The predominant view is that industrialization in Germany took off with a growth spurt in the 1840s, driven by railroads and coal-based heavy industry ([Gerschenkron 1962; Fremdling 1977; Pollard 1990; Pierenkemper and Tilly 2004](#)). Against this view, some scholars argue that industrialization was a more continuous process, induced by deeper historical developments ([Tilly and Kopsidis 2020; Kopsidis and Bromley 2016](#)). Our evidence reveals a shift toward industrialization, centered around research universities, in the early 1800s. Our findings point to a substantially new view of the industrialization process.

2 The Historical Process

In this section, we review the research on German industrialization, including the paucity of evidence before 1840, which has limited study of the research university as a factor driving industrialization. We then discuss the pro-scientific shift at German universities. Finally, to clarify our analysis of spillovers, we provide evidence on the nature of university locations.

2.1 Industrialization in Germany

The timing and nature of the industrialization process in Germany are subject to debate.

An influential body of research dating back to [Sombart \(1909\)](#), [Schumpeter \(1939\)](#), and [Gerschenkron \(1962\)](#) argues that the key shift towards industrialization occurred in a “big spurt” in the 1840s and 1850s. This literature points to the importance of railroads, heavy industry, and large scale banking (see [Hoffmann 1963; Tipton 1976; Fremdling 1977; Pollard 1990; Guinnane 2002; Hornung 2015](#)). Thus [Becker, Hornung, and Woessmann \(2011\)](#) argue

that Germany was “pre-industrial” in the first decades of the 1800s.⁷

A second strand of literature emphasizes the gradual and continuous nature of the industrialization process. [Kaufhold \(1986\)](#) and [Ogilvie \(1996\)](#) present evidence indicating that industrialization was part of a longer-run economic transformation. Building on this scholarship, [Tilly and Kopsidis \(2020\)](#) and [Kopsidis and Bromley \(2016\)](#) argue that the growth of heavy industry and urbanization after the mid-1800s reflected and was caused by very gradual, prior processes of economic and institutional development.

A third strand of the literature argues that significant, and in some sense revolutionary, shifts towards industrialization took place in the late 1700s and early 1800s. The mechanization of textiles in Germany increased rapidly in the early 1800s ([König 1899](#); [Meerwein 1914](#); [Forberger 1958](#); [1982](#); [Kirchhain 1973](#)). Similarly, the adoption and development of steam engines in Germany starting in the late 1700s is considered as an indicator of significant economic change ([Engelsing 1968](#), p. 73; [Kuczynski 1961](#), p. 24, 87).⁸

The role of universities in German industrialization is ambiguous and, we argue, understudied. While research universities developed in the early 1800s, as we detail below, the leading view among historians is that that higher education and scientific training became economically important after 1850, when they provided human capital and innovations for a process driven by the development of railroads and heavy industry ([Landes 1969](#); pp. 151, 187). However, almost all prior research using quantitative methods to investigate the development of industrial or inventive activity studies data from periods after the 1840s, when the first industrial censuses appear and richer patent data are available.⁹ Indeed, as [Tilly](#)

⁷Indeed, a large share of the population was employed in agriculture into the late 1800s ([Kopsidis and Bromley 2016](#)). Meaningful productivity comparisons begin in the 1870s and indicate German manufacturing had not caught up with British manufacturing at that time (e.g. [Broadberry and Burhop 2010](#)).

⁸[Henderson \(1956](#); p. 202) also argues that the origins of German industrialization date from the late 1700s, highlighting blast furnaces, foundries, and engineering works established in the later 1700s. [Mottek \(1960\)](#) argues that a preparatory period starting in the 1780s with the adoption of steam engines and spinning machines set the stage for industrial transition after 1834, when the German customs union was formed.

⁹Panel data from industrial censuses begin with the Prussian census of 1849. In earlier periods, existing data on industry are fragmentary and research has studied unique cross-sectional evidence, notably [Hornung’s \(2014\)](#) analysis of Prussian textile plants in 1802. Prior quantitative research on invention is largely restricted to the patent record ([Streb, Baten, and Yin 2006](#); [Donges and Selgert 2019](#)). However, patent data also do not permit the temporal and spatial comparisons we explore around the reform of universities. Prussia passed the first patent law in Germany in 1815; patent systems in other territories were set up at substantially later dates and under different rules; an agreement harmonizing patent systems was adopted in 1842 ([Donges and Selgert 2019](#); p. 61-3). [Moser’s \(2005\)](#) study of patented and non-patented innovation examines evidence from the 1851 World’s Fair and 1876 Centennial Exhibition, and is also situated in the mid-1800s.

(1991; p. 177) observed more generally, most analytic narratives of German industrialization remain based on study of heavy industry and railroads, but not on quantitative evidence from other sectors or the pre-1840 period, when universities were transformed.¹⁰

While our analysis focuses on shifts in universities precipitated by the French Revolution, the shock we study may also have influenced development through other channels. The Napoleonic invasion of Germany led to legal reforms in some regions, including the abolition of guilds and occupational restrictions starting in the 1790s.¹¹ The Napoleonic wars also disturbed trade, raising effective protection against British imports of cotton textiles (Juhász 2018) and disturbing input supplies, with unclear net effects (Crouzet 1964; p. 579). Our analysis below thus studies how universities shaped invention and industrialization *within* political territories and thus across cities exposed to similar institutional change and shocks.

2.2 The Shift to Science and Technology in Universities

German universities moved to promote science and technology in the period we study, and “the sciences underwent a revolutionary change” (Turner 1987; p. 56). In the 1700s, universities focused on theology and law; in the 1800s, German research universities emerged as world leaders in science and technology (McClelland 2019; Turner 1975).

University investments in scientific research collections provide a unique measure of institutionalized university support for scientific research. Figure 2 shows that the number of scientific research collections at German universities began increasing sharply around 1789/1790, and shifted from a low to a high growth path between 1790 and 1820. These shifts were shared across universities and reflect such examples as the technology collection at Göttingen (1789) and the chemistry collection at Leipzig (1805).

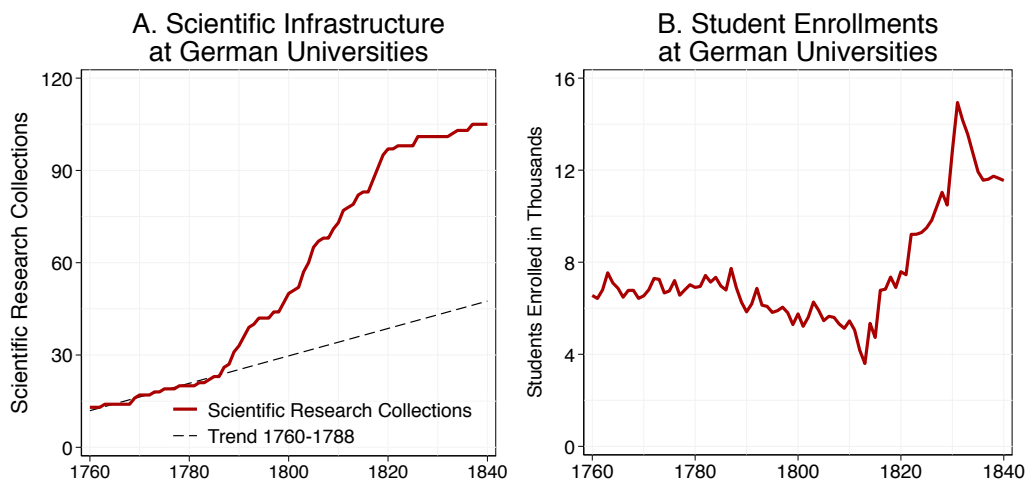
The timing of this shift in the development of research infrastructure is significant. The increase in research collections began during the French Revolution (1789) and pre-dates the Napoleonic invasion of Germany (1805) and subsequent foundation of the university of Berlin (1810), indicating that these factors did not precipitate the process we study.¹² Panel B shows

¹⁰Scholars have for some time pointed to the potential underestimation of development pre-1850. Tilly (2001; p. 157) notes that, “the implications could be far-reaching: Germany’s relative backwardness in the so-called ‘take-off’ period of industrialisation was quite likely significantly less.”

¹¹Acemoglu et al. (2011) find these reforms led to greater urbanization after 1850 in more affected Western regions. However, guilds were not eliminated in the leading industrial region of Saxony until the late 1800s.

¹²Narrative evidence points to the importance of changes starting around 1800. As Böhme and Vierhaus

Figure 2: Scientific Research Collections and Student Enrollments



Panel A plots the number of scientific research collections at German universities, measured by the number of: technological model, chemistry, physics, mineral, and zoology research collections; observatories; and botanical gardens. Panel B plots annual data on the number of students enrolled at German universities. Data on scientific collections at universities are from [Weber et al. \(2013\)](#), supplemented with evidence for Breslau from [Nadbyl \(1861\)](#). Data on university enrollments before 1830 are from [Eulenburg \(1904\)](#) except for Berlin, which is recorded in [Lenz \(1910\)](#). Data on enrollments from 1830 forwards are from [Titze \(1995\)](#).

university enrollments increased with a lag, after 1820, suggesting that any university effects in the early 1800s were not principally driven by increases in student numbers.

The data on research collections reflect a shift in support for the sciences, which is also documented but less systematically recorded in other sources of evidence. For example, “massive state intervention” led to the establishment of “a veritable phalanx of . . . scientific institutions” at Jena in 1803 ([Ziche 2001](#); p. 152 – our translation), but these institutions were only formally recognized by new university statutes in 1821. Similarly, in 1821 the parliament of Saxony granted the university of Leipzig an annual subsidy on condition that the university maintain transparent books, indicating how budget records in the early 1800s provide problematic evidence on research expenses. Surviving evidence on syllabi and courses in the early 1800s are also fragmentary. Partly for this reason, historians have focused heavily on tracing the development of formalized research seminars and institutes with dedicated budget lines, and the formation of separate scientific departments within the “philosophy” faculty, all of which begin to be more systematically recorded in the late 1820s ([Titze 1995](#)).

This pro-science shift in universities involved innovations we would expect to generate ([2002](#); p. 165 – our translation) observe, “the natural sciences in the middle of the 18th century did not yet have the professionalism, reputation, and scientific level that only began to develop fifty years later.”

spillovers into industrial activity.¹³ Research institutes were established to promote the development and commercialization of technology, such as the Physical Mechanical Institute (1802) at Jena (Ziche 2001; p. 193). Professorships in scientific subjects that generated useful knowledge were created in philosophy departments, such as the chair in Chemistry at Jena (1789) and the applied science section in the Philosophy faculty at Heidelberg (1803) (Martin 2007; Hinz 1961). Biographical evidence points to the importance of inventions developed around universities and by university graduates, which we confirm quantitatively (Section 5). Narrative evidence also indicates that university graduates established manufacturing firms and that mechanics attended universities as non-matriculated students after 1800.¹⁴

Political events shifted the supply of and demand for scientific knowledge in Germany, leading to concrete changes in universities. Palmer (2014) summarizes the German response to the French Revolution as a “revolution of the mind” (see also Blackbourn 2003). On the supply-side, the French Revolution inspired pro-science intellectuals in a massive cultural shift (Whaley 2012; p. 601).¹⁵ On the demand side, the priorities of policy makers also shifted and increasingly science and technology were viewed as important for a broader project of modernization in the context of the shifting political environment. The Napoleonic invasion of Germany further promoted the modernization of university education, which was famously advocated by Prussian Interior Minister Wilhelm von Humboldt.

It is important to note that other aspects of education shifted in the period we study. Prussia enacted a major reform of primary education in 1809 in response to military defeat in 1806 (Kindleberger 1975; p. 260) and schooling more generally expanded. In our quantitative analysis, we therefore introduce controls for time-varying territory-level factors, such as educational reforms, and gather evidence on all schools established in every city, from

¹³Today, in era of lower transport costs, many spillovers remain local. See Audretsch and Feldman (2004).

¹⁴Professor Johann Heinrich Voigt (1751-1823) observed mechanics attending his mathematics and physics lecture at Jena to learn the science behind their trade, and established a “physical-mechanical” institute in 1802 to: combine university teaching and the development of new instruments; promote the commercialization of technologies; and enable visiting mechanics to set up laboratories (Ziche 2001; pp. 227-229). The career of Johann Beckmann (1739-1811), Professor at Goettingen and coiner of the word technology, also provides evidence on spillovers between universities and business. Beckmann’s university lectures drew merchants and craftsmen who already had acquired business training (Marino 1995; p. 359).

¹⁵For example, Kant wrote his *Critique of Judgment* (Kant 1987 [1790]; p. xxix) in a period in which the French Revolution “occupied him entirely,” according to his friend Reinhold Jachmann. Following Kant’s intervention, “the ideal of a rigorous science experienced a spectacular upsurge” (Van Bommel 2015; pp. 12-14). Conceptually, Karl Marx (1975 [1842]; p. 213) noted that Kant’s work should be considered, “the German theory of the French Revolution.” See also Marcuse (1960; pp. 3-4) on how major innovations in German philosophy and intellectual life developed, “largely as a response to the challenge from France.”

elementary through higher technical schools.¹⁶ To preview, we find the effects of universities hold controlling for the territory-level factors and more local variation in the development of other types of schooling. In addition to schools, “economic societies” emerged to promote the development of knowledge (Cinnirella, Hornung, and Koschnick 2022), but such societies do not account for the effects of universities on manufacturing as we detail below.

2.3 The Locations of Universities

A key question for our analysis concerns the potentially endogenous location of universities. The historical evidence on the location of universities is therefore important in motivating the research designs in our quantitative analysis and in interpreting the data. To clarify the variation we study it is helpful to distinguish locations with historic universities active throughout our period and locations where universities either opened or closed.

Most universities were active throughout our period at fixed locations. In Germany, these *historic universities* were “generally located in small towns” at locations that were “already too fixed to be manipulated by the new states” in the 1800s (Segal 2018; p. 57).¹⁷ The prestige of historic universities in small provincial towns meant they could not be shifted (Rüegg 2004b). These universities were founded in the pre-industrial age and were designed to produce non-scientific human capital and knowledge.

However, French military control over German territories did lead to the opening and closure of universities. These changes in university locations were driven by military events. Consider the three new universities. The university at Berlin (1809) was founded by the Prussian authorities to offset the loss in 1807 of the university at Halle due to military defeat (McClelland 2008; p. 50); the university of Bonn (1818) was founded to offset the closure of the nearby university at Cologne in 1794 during the French occupation; and the university of Ingolstadt was transferred to Landshut in 1800 after the French invasion, and from there to Munich in 1825.¹⁸ Historical research also indicates that the closure of universities reflected

¹⁶As discussed below, we also consider the role of technical “higher schools” (*Technische Hochschulen*), which were established decades into the process we study and, as a rule, in capital and not university cities (e.g. Karlsruhe in 1825, Darmstadt 1826, Munich 1827, Dresden 1828, Stuttgart 1829, and Hannover 1831).

¹⁷The university of Leipzig was exceptional in being in an important city in our study area. The universities at Vienna and Königsberg, were also in major cities, but are outside our study area.

¹⁸Before the Napoleonic wars, Prussia’s principle university was in Halle. The Treaty of Tilsit (1807) stripped Prussia of half its territory, including Halle, depriving it of its university (Dieterici 1836; p. 60). Bonn is 34 kilometers from Cologne. This change generated limited local shifts in exposure to a university.

political factors that were independent of the strength or quality of the universities (Rüegg 2004b; Turner 1987).¹⁹ However, closures were concentrated in Western regions, and this provides one motivation for our examination of regional differences below.

The natural concern is that university locations may still have been endogenous, historical evidence on the role of political shocks notwithstanding. Our quantitative analysis addresses questions concerning the potential endogeneity of university locations in several ways. We show that cities nearer to universities had no advantages, and no differences in trends, in manufacturing or technical knowledge before the political shocks of the French Revolution and the Napoleonic wars. We also show that our findings hold when we restrict our analysis to study only the plausibly exogenous variation in university exposure shaped by historic universities open throughout our period, and thus when we take university exposure driven by changes in university locations off the table. Our findings also hold when we study exposure to universities open before the French Revolution. See Section 4 below.

3 Data

3.1 Manufacturing

We gather information on manufacturing activity from the *Deutsches Städtebuch* (Keyser 1939-1974), an encyclopedia of German cities. The *Städtebuch* entries describe the economic development of cities, including the history of manufacturing activities and establishments. We code, date, and classify all manufacturing activities with two-digit SIC codes. The underlying observation in our data is a manufacturing “event”: the opening or presence of an establishment or a specific type of manufacturing in a city-year. For example, in 1801 the *Städtebuch* records: a printing establishment (*Buchdruckerei*) in Schwabach; a machine factory (*Machinenfabrik*) in Mannheim; a wire factory (*Drahtfabrik*) in Allersberg; a paper mill (*Papiermühle*) in Hoehr-Grenzhausen; a tobacco manufacture (*Tabakfabrikation*) in Vierraden; and a textile weaving establishment (*Tuchweberei*) in Euskirchen.

Several aspects of the data are important to clarify. First, our data record the opening and in some cases presence of establishments. Second, our measure of events is a *proxy* for changes in manufacturing. Third, the dating of some observations in the *Deutsches Städtebuch* is

¹⁹We test and confirm that there were no significant differences in *ex ante* enrollment growth for the universities that were closed or remained open after the French Revolution (Appendix B).

approximate.²⁰ We aggregate to twenty-year periods and focus on the shifting relationship between manufacturing and proximity to universities conditional on the variation shared by all cities in a given period. Fourth, the data cover 2,254 settlements that received formal city rights. The “cities” we study thus range from very small towns to major urban centers.

To assess the data, we test how well our measure of manufacturing explains the number of factories and workers recorded in the Prussian Census. We study how our measure explains factories and workers at the two-digit industrial classification level recorded at the county-level data in the first large body of administrative data, the Prussian Census of 1849 (Becker et al. 2014). Our measure of changes in manufacturing, observed over the 1820s and 1830s, strongly predicts the cross-sectional administrative data from the 1840s. We estimate elasticities close to one in almost every industry. We report this analysis in Appendix A.

3.2 Scientific and Technological Discovery

We construct data on scientific and technological discoveries building on Darmstaedter, du Bois-Reymond, and Schaefer’s (1908) *Handbuch zur Geschichte der Naturwissenschaften und der Technik*, which catalogues major inventions and discoveries in our period. Darmstaedter’s project was produced by 60+ contributors, including four Nobel Laureates. The handbook records inventions, pure science break-throughs, early technology prototypes, and the adoption or installation of commercially viable technologies.²¹ The handbook describes and dates each contribution and identifies the scientists or inventors responsible.

We build our database as follows. First, we match discoveries to city locations and gather information on the educational background of each scientist and inventor. To do this, we construct biographical evidence on the lives, employment, and educations of scientists and inventors from the *Deutsche Biographie*, the *World Biographical Information System*, and historical sources. Second, we distinguish between scientific discoveries and practical inventions, most of which have industrial applications. We classify the practical inventions in our data with SIC codes for the industries in which they could be used or applied. Our database comprises 1,937 major discoveries in the 2,254 cities we study 1760-1899.²²

²⁰Some establishments are recorded as opening “around” a given year or with even more roughly defined dates, such as “in the 19th century”. We exclude the latter observations from our baseline analysis.

²¹In terms of the lexicon suggested by Joseph Schumpeter, our data include invention and innovation observations, and observations where the invention-innovation distinction is ambiguous (c.f. Rosenberg 1976).

²²We focus analysis on discoveries for which location is unambiguous. Our findings are robust to flexibly

Examples of observations in our data are as follows. In 1801, university-educated chemist Franz Karl Achard develops inventions for beet sugar production (SIC food) in Berlin and establishes a factory in Silesia. In 1807, university-educated chemist Christian Friedrich Bucholz develops sulfur milk (SIC chemicals) at Erfurt. In 1811, Friedrich Krupp develops processes for steel and cast iron production (SIC primary metals) at Essen and he founds Krupp steel company. In 1820, the university-educated chemist and inventor Ernst August Geitner develops chromium-acid based dyes (SIC textiles) at Schneeberg, where he sets up a chemicals factory. The variation in the education and location of individual knowledge producers which these examples illustrate motivates our quantitative analysis, in which we test whether invention shifted towards universities and examine how manufacturing developed in sectors more or less reliant on inventions by university-educated inventors. Appendix Tables [A2](#) and [A5](#) provide further details on the data.

The data have advantages and limitations. They provide unparalleled evidence on practical invention and basic science and cover time periods for which no consistent German patent data exist. The data can be used, as the authors of the handbook indicate, to study the development of science and technology, including “their condition in... changing political conditions” ([Darmstaedter and du Bois-Reymond 1904](#); p. II – our translation). By construction, the data record major discoveries that can be attributed to individuals.

3.3 Additional Sources

We gather additional data as follows. Data on the location of universities are from [Rüegg \(2004a;b\)](#). We collect information on all schools opened in the cities we study, coding evidence from [Keyser \(1939-1974\)](#). We construct evidence on territory-level free enterprise laws following [Acemoglu et al. \(2011\)](#), data on railroad connections from [Kunz and Zipf \(2008\)](#), and data on coal deposits from [Asch \(2005\)](#). We gather information on the adoption of mechanized production technologies from [Forberger \(1982\)](#) and on exhibits and prizes at the Crystal Palace World’s Fair as described below. For details on all data see Appendix [A](#).

incorporating observations where there is ambiguity over locations.

4 Universities and Manufacturing

4.1 Stylized Facts

Table 1 presents the key stylized facts in our analysis. Before 1800, cities nearer to universities had no advantage in manufacturing, which we use as our main measure of industrial activity. After 1800, manufacturing increased and shifted towards universities, consistent with our first hypothesis. The shift in manufacturing towards cities with universities is particularly pronounced in the period between 1800 and 1859. This core period begins with major shocks to politics and universities. It closes when the costs of transportation fell significantly, after the 1850s, due to the development of railroads ([Fremdling and Hohorst 1979](#); [Wrigley 1961](#)).

Table 1: Universities and the Development of Manufacturing

Time Period	(1)	(2)	(3)	(4)
	Any Manufacturing: Mean		Total Manufacturing: Sum	
	Close to University	Far from University	Close to University	Far from University
1760-1799	0.10	0.12	181	186
1800-1859	0.44	0.36	1427	988
1860-1899	0.30	0.30	785	708

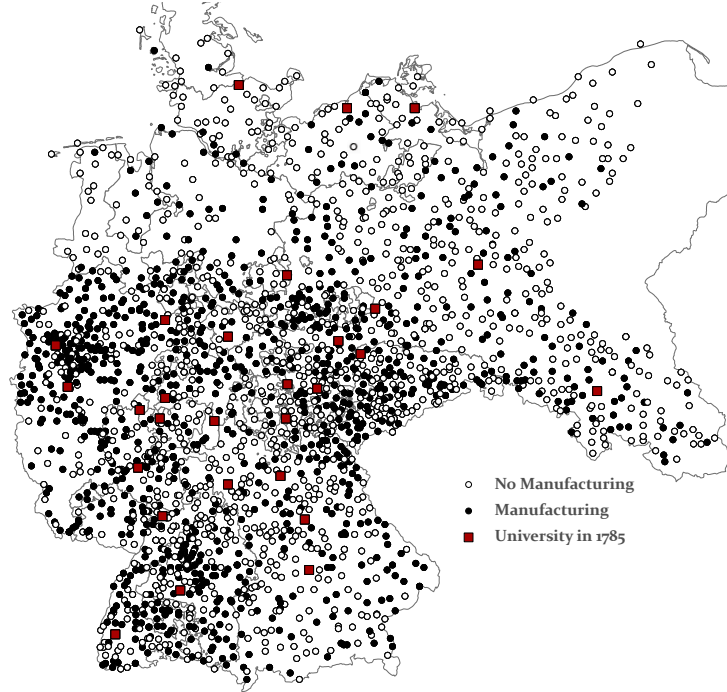
This table reports summary statistics on manufacturing for 2,254 cities recorded in the *Deutsches Städtebuch* ([Keyser 1939-1974](#)). Towns “close” to a university are defined as those below median distance to a university in 1785. Towns “far” from a university are above median distance to the nearest university in 1785. Columns (1) and (2) report the mean of an indicator for any manufacturing events in a town-time-period. Columns (3) and (4) report the total number of manufacturing events.

To clarify the spatial comparisons we study, [Figure 3](#) maps the locations of towns and universities in our analysis and the pattern of manufacturing between 1800 and 1859.

The manufacturing events we study proxy for *changes* in manufacturing activity. The manufacturing events we observe cumulatively over the first half of the 1800s predict the number of workers and the number of factories recorded in the 1849 Prussian Census at the county-by-industry level, with almost unit elasticities, as we show in [Appendix A](#).²³

²³In contrast, the manufacturing events we observe in the immediate years before the census provide a weaker and less precise prediction of the number of factories and number of workers active in the late 1840s.

Figure 3: Manufacturing in German Cities 1800-1859



This map presents evidence on manufacturing across 2,254 cities recorded in the *Deutsches Städtebuch* (Keyser 1939-1974). Cities with any manufacturing events 1800-1859 are indicated with black circular markers. Cities with no manufacturing events 1800-1859 are indicated with white circular markers. The locations of universities as of 1785 are indicated with larger square markers (shaded red in online version).

4.2 Quantitative Analysis

A. Research Designs. To test our first hypothesis, that manufacturing increased differentially around universities after 1800, we estimate regression models of the form:

$$manufacturing_{it} = \sum_s \beta_s (university_i \times time_s) + \theta_i + \delta_t + \epsilon_{it} \quad (1)$$

The outcomes we study are the number of manufacturing events in a city-time-period, with time measured in twenty year periods, and an indicator for any manufacturing, which captures the extensive margin of economic activity. The treatment variable $university_i$ is a time-invariant indicator for cities close to universities, defined as below median distance, which is approximately 60 kilometers. The θ_i and δ_t are city and time fixed effects. We confirm the relationship between manufacturing and proximity to universities using linear and flexible measures of distance as discussed below (Subsection F).

The analysis addresses questions about the *potential endogeneity* of university locations

as follows. We first estimate the relationship between universities and manufacturing using the locations of universities in the 1800s, which in a few cases could reflect the endogenous selection of locations in the early 1800s. We then restrict the analysis to cities whose university exposure did not shift due to potentially endogenous changes in universities and confirm our findings. This shows that the opening of universities at Berlin and Munich does not explain our findings.²⁴ We further document that new universities had no differential effects on manufacturing beyond those observed around existing universities in Appendix B.

The analysis takes steps to ensure that *inference* is not biased by spatial autocorrelation. Standard errors are estimated allowing for arbitrary forms of spatial autocorrelation, following Conley (1999). We also introduce a rich set of control variables that vary across space and time and absorb underlying spatial correlation. These include territory-by-time fixed effects for each of the 44 territories of the historic German Confederation, city-level factors that vary over time such as the number of schools and proximity to railroads, and variables absorbing the time-varying implications of initial differences in city development.²⁵

B. Baseline Analysis. Figure 4 presents baseline estimates of the shift in manufacturing towards universities after 1800. We focus on shifts over two longer periods suggested by historical research, 1800-1859 and 1860-1899, indicated with shaded boxes. To clarify the underlying variation, we also report flexible period-by-period estimates.

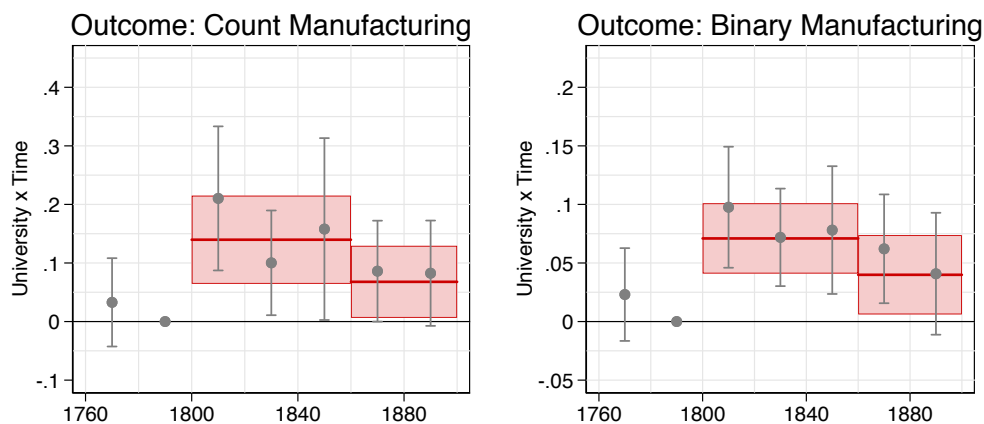
We find that the number of manufacturing events and the probability of any manufacturing increased differentially in cities nearer to universities after 1800, consistent with our hypothesis. We observe these shifts when we examine exposure to universities active in the 1800s (Panel A) and when we restrict analysis to cities whose proximity to universities did not change over our period (Panel B). The flexible models show there was no trend in manufacturing towards universities before 1800. If anything, there was a slight pre-trend away from universities. We expand our analysis to also test for pre-trends in urban construction, which is a core indicator of pre-industrial development, in Subsection G below. The statistical significance of the estimated shift in manufacturing is not contingent on the distance over which we allow for spatial autocorrelation (see Appendix C for details).

²⁴We also show that results are similar when we study exposure to historic university locations as of the 1780s, including several locations where universities closed in the 1790s and early 1800s (see Appendix B).

²⁵We show inference is robust to different spatial thresholds, holds accounting for potential serial correlation following Bertrand, Duflo, and Mullainathan (2004), and is not driven by spatial noise in Appendix C.

Figure 4: Universities and New Manufacturing

A. All Cities



B. Cities with No Change in University Exposure



This figure presents regression estimates in which the outcomes are the count of manufacturing events (mean 0.27) and an indicator for any manufacturing events in a city-period (mean 0.17). The treatment variables are interactions between an indicator for cities close to universities in the 1800s and time period indicators. The university exposure indicator (“University”) is 1 for cities below median distance to a university in the 1800s. Panel A examines all cities ($n=2,254$). Panel B restricts analysis to cities whose university exposure did not change between the late 1700s and the 1800s ($n=1,686$). Each graph reports estimates from two regressions. The first regression estimates the response of manufacturing to universities in two post periods: 1800-1859 and 1860-1899, relative to the reference period 1760-1799. These estimates and 95% confidence intervals are represented by shaded boxes. The second regression estimates a flexible model in which “University” is interacted with time period indicators, with 1780-1799 the reference period. All models include city and time fixed effects. Standard errors and 95% confidence intervals estimated following [Conley \(1999\)](#) allow for arbitrary spatial correlation within 25 km (see Appendix C for estimates examining a range of distances).

The results show that the shift in manufacturing is not driven by potentially endogenous changes in university locations. In particular, Panel B shows that the university effect is observed when we exclude local spillovers from new universities. We confirm that new

universities were associated with no differential shifts in manufacturing in Appendix B. We do, however, observe that the university effect over the 1800-1859 period is slightly smaller across all cities (Panel A) than across cities for which university exposure does not change (Panel B). This is consistent with new universities generating spillovers that develop only over time. But given that the shifts in the locations of universities varied across regions, these patterns also point to the potential importance of regional differences, and of the within-region variation, in university exposure and industrialization.

The decline in the “university effect” after 1860 implies cities near universities pull away more slowly, not that the university effect on the *level* of manufacturing vanishes. This is because the “events” we study reflect *changes* in manufacturing and proxy for *flows*, and as such predict the stock of factories by industry-and-location in the 1848 Prussian Census (Appendix A). A negative post-1860 effect is thus needed to offset the positive effect 1800-59.

C. Regional Factors. Several regional factors have been emphasized as determinants of economic activity in the period we study, which in theory could be correlated with proximity to universities and thus explain our baseline estimates. First, regional variation in institutional change shaped development. [Acemoglu et al. \(2011\)](#) document that legal changes instituted during the Napoleonic occupation of Western regions of Germany led to greater urbanization in these regions after 1850. More generally, historians suggest that German industrialization was shaped by “regionally varying, gradual institutional evolution,” including schooling reforms ([Tilly and Kopsidis 2020](#); p. 11). Second, trade shocks arising in the aftermath of the French Revolution varied regionally. [Juhász \(2018\)](#) finds that the Napoleonic blockade of England generated a differential increase in import protection to the French cotton spinning industry in regions nearer to England, raising the possibility of similar patterns in Germany. Third, religion and basic human capital varied regionally. Literacy was higher in Protestant regions of Germany and strongly predicts industrial activity in the late 1800s ([Becker and Woessmann 2009](#); [Becker, Hornung, and Woessmann 2011](#)).

We address questions about the role of time-varying regional factors in several ways. First we investigate the relationship between universities and manufacturing both within regions and within territory-x-time-period cells. Our regional analysis assesses whether university effects are observed in regions *not* treated by the legal changes [Acemoglu et al. \(2011\)](#) study and in Eastern regions far from England, which were the *least* exposed to

increases in effective protection from British cotton. Our analysis studying university effects controlling for factors that vary at the territory-x-time level absorbs all the variation in economic institutions studied by [Acemoglu et al. \(2011\)](#), controls for shifting territory-level factors such as schooling reforms, and accounts for almost all the spatial variation in the trade shocks due to the Napoleonic blockade across the 44 German territories we study, and differences in religion. We consider potential residual, within territory variation below.

Table 2 presents our estimates. Panel A studies all cities and measures university exposure based on locations in the 1800s, while Panel B restricts analysis to cities whose university exposure did not change as a result of potentially endogenous shifts in locations. Columns 1-5 study the number of manufacturing events as an outcome. Column 1 presents estimates which replicate Figure 4. Column 2 shows that in Eastern Prussia we find a somewhat larger effect in an area not treated by Napoleonic institutional reforms and not treated with large increases in protection due to the blockade.²⁶ Column 3 studies cities in Western Prussia, where Napoleonic institutional changes were concentrated and several universities were closed in the Napoleonic era. Here we find a slightly weaker and imprecisely estimated university effect studying the number of manufacturing events. Outside Prussia we find a significant but quantitatively somewhat smaller estimate, as shown in column 4.

The positive university effect after 1800 remains statistically and economically significant when we control for factors that vary over time at the territory-level (column 5). We study the relationship between universities and manufacturing *within* territory-x-time cells, locating cities in 44 territories comprising the German Confederation as of 1815, which we consider as time invariant regional identifiers. To clarify, for the Principality of Brunswick, our analysis compares the evolution of manufacturing in 9 towns close to and 9 far from a university, conditional on the variation shared by all cities in Brunswick in a period. In the Province of Saxony, we compare 91 towns close to and 63 far from a university. Details on the within-territory variation are provided in Appendix A. The comparisons in column 5 thus control for changes in territory-level legal regimes, educational reforms, and trade shocks.

Our findings are somewhat stronger when we study the extensive margin of manufacturing

²⁶We provide further evidence against the trade shock hypothesis below, showing that while the protection effects of the Napoleonic blockade were specific to cotton spinning ([Juhász 2018](#)), the university effect on German industry was highly significant in industries other than textiles. In addition, the expansion in German cotton spinning during the Napoleonic blockade was concentrated *far* from England in Saxony.

Table 2: Universities and Manufacturing by Region

	(1)	(2)	(3)		(4)	(5)	(6)	(7)	(8)		(9)	(10)
			Variation Studied			Within Territory × Period	All Germany	Eastern Prussia	Western Prussia	Variation Studied		Outside Prussia Territory × Period
<i>A: All Cities</i>												
		Outcome: Count Manufacturing					Outcome: Binary Manufacturing					
University × 1800-1859	0.14*** (0.04)	0.19** (0.08)	0.16 (0.11)	0.11*** (0.04)	0.07** (0.03)	0.07*** (0.02)	0.10*** (0.03)	0.11*** (0.04)	0.04** (0.02)	0.04** (0.02)	0.04** (0.02)	0.04*** (0.01)
University × 1860-1899	0.07** (0.03)	0.19*** (0.06)	0.02 (0.08)	0.02 (0.04)	0.04 (0.03)	0.04** (0.02)	0.11*** (0.03)	0.03 (0.04)	-0.00 (0.02)	-0.00 (0.02)	0.01 (0.02)	0.01 (0.02)
City FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No
Territory × Time FE	No	No	No	No	Yes	No	No	No	No	No	No	Yes
Observations	15778	3717	2408	9653	15778	15778	3717	2408	9653	9653	15778	15778
Mean	0.27	0.23	0.43	0.25	0.27	0.17	0.14	0.24	0.16	0.16	0.17	0.17

B: Cities With No Change in University Exposure

	Outcome: Count Manufacturing			Outcome: Binary Manufacturing							
University × 1800-1859	0.18*** (0.04)	0.30*** (0.10)	0.16 (0.13)	0.11** (0.05)	0.10** (0.04)	0.09*** (0.02)	0.14*** (0.04)	0.13** (0.05)	0.05** (0.02)	0.05** (0.02)	0.06*** (0.02)
University × 1860-1899	0.07* (0.04)	0.30*** (0.08)	-0.13 (0.13)	-0.01 (0.04)	0.03 (0.04)	0.03* (0.02)	0.16*** (0.04)	-0.07 (0.06)	-0.02 (0.03)	-0.02 (0.03)	-0.01 (0.02)
City FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No
Territory × Time FE	No	No	No	No	Yes	No	No	No	No	No	Yes
Observations	11648	2779	1323	7546	11648	11648	2779	1323	7546	7546	11648
Mean	0.26	0.21	0.43	0.26	0.26	0.16	0.14	0.25	0.16	0.16	0.16

This table reports regression estimates in which the outcome is the count of manufacturing events (columns 1-5) or a binary indicator for manufacturing events (columns 6-10) at the town- \times -time-period level. The unit of observation is a town-period: 2254 towns examined in 20-year time periods, 1760 to 1899. “University \times 1800-1859” and “University \times 1860-1899” interact an indicator for towns close to a university with indicators the 1800-1859 and 1860-1899 periods, respectively. In Panel A, “University” is defined as below median distance to universities operating in the 1800s. Panel B restricts to cities with no change in “University” from the 1700s through the 1800s. All regressions include city fixed effects. The “Territory \times Time” fixed effects in column 6 interact indicators for 44 territories, defined as of 1815, with time period indicators. Columns 2-5 examine subsets of the data relative to the set of towns in Prussia as of 1849. Standard errors allow for arbitrary spatial correlation within 25 kilometers following the methodology of [Conley \(1999\)](#). Statistical significance at the 90, 95, and 99 percent confidence level denoted “*”, “**”, and “***”, respectively.

(Panel A, columns 6-10). We find that universities are systematically associated with a higher probability of their being manufacturing events in a city-period. This positive effect is statistically significant in all regions and concentrated in the 1800-1859 period.

These findings are not driven by the endogenous selection of new university locations. Our estimates for the 1800-1859 period are larger when we restrict analysis to cities for which “university treatment” did not change over our period (Panel B). We confirm that new universities did not lead to differential increases in manufacturing in Appendix B.

D. Factors Varying Within Regions. We extend our analysis to consider factors that vary within regions. Prior research emphasizes four leading factors with the potential to be confounders in our setting. First, the prior development of proto-industrial *early manufacturing* varied across cities and potentially influenced the development of manufacturing in the 1800s (Kopsidis and Bromley 2016; Kreidte, Medick, and Schlumbohm 1977). Second, *railroads* promoted manufacturing in ways that varied locally (Fremdling 1977; see also Hornung 2014). Third, proximity to *coal* deposits became a factor for industrial activity in Germany, particularly after 1840 as coal-using technology diffused (Wrigley 1961). Fourth, *schooling* was a potential factor in local development (Lundgreen 1975).²⁷

We account for and study these factors as follows. (1) *Early manufacturing*: we gather data on city-level manufacturing before 1760 from the *Städtebuch* and test whether cities with such early manufacturing enjoyed an increase in growth after 1800. (2) *Railroads*: we measure and control for railroad connections period-by-period with a binary variable for cities on railway lines. (3) *Coal*: we classify cities close to or far from coal deposits, measured as above or below median distance, and test whether cities close to coal enjoyed developmental advantages after 1800 or after 1840. (4) *Schooling*: we construct a measure of local schooling by coding information on all schools in the cities we study, period-by-period, but focus on the role of “higher schools,” which provided advanced training outside the university system. Higher schools include *Gymnasia*, *Gewerbeschulen* (technical schools), *Lyzeen* (Lyceum), and *Realschulen*.²⁸ We focus on higher schools because they were unique

²⁷The diffusion of knowledge was also promoted by “economic societies,” which were set up in some cities (Cinnirella, Hornung, and Koschnick 2022). However, the university effects we estimate hold controlling for economic societies, which were not themselves correlated with shifts in manufacturing. See Appendix B.

²⁸Our results are also robust to controlling for the presence *Technische Hochschulen*, which were established starting in the 1820s and evolved only in the late 1800s to become Germany’s “technical universities.” We find a small and less precisely estimated relationship between *Technische Hochschulen* and local manufacturing.

in having a strong relationship with manufacturing over the first half of the 1800s. To clarify and preview, we find that the establishment of elementary, middle, and continuing education schools have little explanatory power for the development of manufacturing until the late 1800s and are not confounders in our analysis.²⁹ We provide details in Appendix F.

To clarify our findings relative to the literature, we also consider the implications of territory-level “free enterprise” (*Gewerbefreiheit*) laws, which spread in a staggered manner across the territories of the German Confederation, and shaped urbanization after 1850 (Acemoglu et al. 2011). The effects of these institutions can be estimated in models studying variation *across* territories, but are absorbed in analyses with territory- \times -time fixed effects.

Table 3 presents our estimates. The estimated post-1800 effects of universities hold virtually unchanged when we account for differences in early manufacturing, proximity to coal, exposure to free enterprise laws, railroad connections, and the presence of higher schools (Table 3 column 1 compares to Table 2 column 1). The estimates on these factors are, however, significant and in several instances similar in magnitude to the university effect.

To examine the timing of the relationships shaping manufacturing more closely, we restrict our analysis to periods before 1840 (column 2). Over this period, before railways were developed, the impact of universities is almost unchanged, while the association between free enterprise laws and manufacturing declines and is only borderline statistically significant.³⁰ A history of early manufactures was strongly associated with manufacturing in this pre-railroad period, consistent with continuities in development operating alongside the university effect.

We extend our analysis to consider the timing of the relationship between higher schools and manufacturing (column 3). We introduce leads and lags for higher schools. We find that the university effect is stable and only *future* higher schools have a strong, statistically significant relationship with current manufacturing. This indicates that higher schools were established after manufacturing increased and the endogeneity of schooling. However, as territory-level educational reforms were passed starting in Prussia in 1809, it natural to question whether the university effect holds controlling for territory-by-time variation.

When we study the within-territory variation, the university effect remains highly

²⁹Prior research documents a positive relationship between elementary education, literacy, and manufacturing in late 1800s Germany (Becker, Hornung, and Woessmann 2011; Becker and Woessmann 2009). We find elementary and middle schools do explain manufacturing *after* the mid-1800s (Appendix F).

³⁰We consider the period to 1839 to be the pre-railroad era. The first railway construction in Germany dates from the late 1830s. Our results are robust to restricting to years before any railroads were built.

Table 3: Universities and Other Factors Varying Within Regions

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

This table reports regression estimates with variables defined as above. Columns 1-4 study all manufacturing measured in counts. Columns 5 and 6 study counts of manufacturing in non-textiles and new industries, respectively, with new industries defined as those industries in which a given city had no pre-1760 manufacturing. Columns 7-8 study a binary outcome for any manufacturing in all industries. “Railroad Connection” and “Free Enterprise Law” are indicators constructed from [Kunz and Zipf \(2008\)](#) and coded following [Acemoglu et al. \(2011\)](#), respectively. “Early Manufactures \times Post-1800” interacts an indicator for post-1800 periods and an indicator for pre-1760 manufacturing activity. “Coal \times Post-1840” and “Coal \times Post-1800” interact an indicator for proximity to coal fields with time period indicators constructed from [Asch \(2005\)](#). “Higher School” is an indicator measuring the presence of secondary schools. Territory- \times -Time fixed effects as in Table 2. Standard errors allow for arbitrary spatial correlation within 25 kilometers following methodology of [Conley \(1999\)](#). Statistical significance at the 90, 95, and 99 percent confidence level denoted “*”, “**”, and “***”, respectively.

significant and large relative to the mean, but declines in magnitude to 0.07 (column 4).

These findings indicate the importance of universities and the limited role of basic education in the process we study. Given that our research design controls for time-varying territory-level factors (such as educational reforms) and the establishment of city-level schools, for schooling to account for our results the quality of or returns to schooling would have to differentially increase near universities in the early 1800s. While unobserved shifts in school quality could theoretically provide a *channel* for the university effect, this is not a plausible explanation for several reasons. First, we observe significant university effects on industrial activity in territories without schooling reforms and in the first decades of the 1800s, such as [XYZ]. Second, reforms targeting the quality of education could benefit from spatial spillovers from universities, but developed with substantial lags. Prussia required teacher certification starting 1810 and made final exams (*Abitur*) universal in 1812, but experienced a school construction boom between 1820 and 1835 (Meisenzahl 2015; p. 311), and phased reforms in over the 1820s and 1830s (Rang-Dudzik 1981).³¹ The cohorts impacted by changes in schooling in Prussia emerged to influence invention and industry in decades after 1840. Indeed, we find that elementary and middle schools do not explain manufacturing before the mid-1800s and do so afterwards. See Appendix F.

We next investigate the mechanisms driving our result. We first test and find the university effect is strongly present in non-textile industries, within-territory (column 5). This indicates that the spatial effects of the Napoleonic blockade, which Juhász (2018) finds were specific to the cotton industry, do not explain our findings.³² We next test whether the university effect on manufacturing after 1800 was concentrated in “new” industries, defined as activities in two-digit SIC industries in which that city had no manufacturing before 1760.³³ When we study the development of new manufacturing industries, the post-1800 university effect remains almost unchanged. This implies that the university effect is almost

³¹For example, core provisions of the 1816 reform of Prussian grammar schools was not compulsory, and teachers were required to have passed science exams only starting in 1831 (Rang-Dudzik 1981; p. 219-21).

³²Juhász (2018) effectively measures the positive protection effects of the Napoleonic blockade across French administrative districts with “distance to England” and shows these effects were specific to cotton spinning and not enjoyed in other sectors. Our analysis studying *within*-territory variation already takes almost all geographic variation off the table. However, the fact that university effects are present outside the textiles industry further indicates that Napoleonic blockade effects cannot plausibly explain our results.

³³For a city with no historical textile industry, activities in textiles are “new”; such activities are not new in cities with textiles before 1760. At the two digit SIC level, almost no industries are globally “new” in our period. We study the relationship between universities and technical change within textiles in Section 6.1.

entirely accounted for by new industries (compare column 6 with column 4). In contrast, the effect of “early manufacturing” on new industries is approximately half the size of the effect for all industries. Thus while universities and early manufacturing both explain patterns of change after 1800, in relative terms universities explain new activities more than old.

Finally, we study a binary measure recording whether there is any manufacturing in a city-time-period. We find that university exposure strongly predicts the presence of manufacturing after 1800 (columns 7 and 8), whereas early manufacturing is not a significant factor, indicating the importance of universities for the extensive margin of manufacturing activity. We again find that manufacturing precedes the establishment of higher schools.

E. Variation in the Size of Universities. Enrollments indicate the influence and quality of historic universities (McClelland 2008). We therefore test whether the relationship between universities and manufacturing was greater for cities near large universities. We re-estimate our baseline models with two separate measures of time-varying treatment: being near a “Large University” and being near a “Small University.” We measure size by average enrollments 1800-1830, which were in stable in relative terms, defining “large” as the top 7 and “small” the bottom 8. We focus on cities for which the nearest university was neither Berlin nor Munich, as these began enrolling students after 1810.

Figure 5 shows that manufacturing increased more after 1800 in cities close to large universities. Cities exposed to large universities experienced 0.16 more manufacturing events 1800-1859 than cities far from universities. In contrast, cities near smaller universities experienced only 0.07 more manufacturing events and this effect is not statistically significant. For 1800-1859 the difference between the large and small university effects is significant at the 90% level. By the late 1800s, the large-small difference is highly significant. The negative relationship between small universities and manufacturing 1860-99 implies a reversion to the mean and effectively no difference in growth over the period 1800 to 1899.

F. Flexible Estimates of the Role of Distance. Our baseline analysis comparing cities close to and far from a university enables us to directly compare the “university effect” to that of other factors. However, it is natural to question how spillovers varied with distance more flexibly or reflected exposure to universities more generally.

We first extend our analysis to examine how manufacturing shifted after 1800 for cities in different quantiles of distance distribution. Figure 6 presents estimates on the interactions

Figure 5: University Size and Shifts in Manufacturing

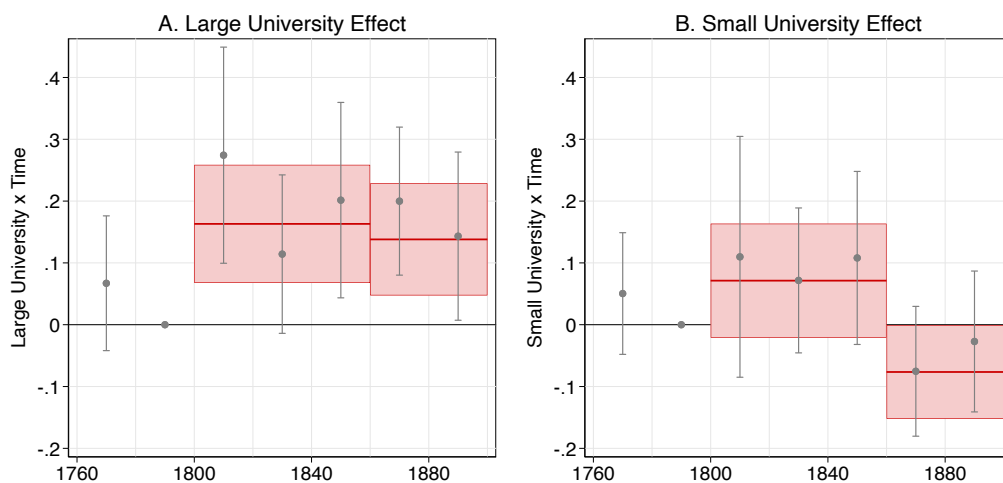


Figure presents regression estimates of spillovers from large and small universities. The baseline regression model is adjusted to include separate interactions between both (A) an indicator for cities near a “Large University” and time indicators and (B) cities near a “Small University” and time indicators. The reference period is 1760-1799 in the model with two post periods (boxes) and 1780-1799 in the flexible model (bars). Panel A plots large university estimates. Panel B plots small university estimates. This analysis restricts to 1,623 cities ($n = 11,361$) for which the nearest university was neither Berlin nor Munich, which opened in 1810 and 1826, respectively. “Large” designates the 7 largest universities (Göttingen Halle, Heidelberg, Jena, Leipzig, Tübingen, and Würzburg) and “Small” the 8 smallest (Breslau, Erlangen, Freiburg, Giessen, Griefswald, Kiel, Marburg, and Rostock). Graph shows 95% confidence intervals estimated with standard errors allowing for arbitrary spatial correlation within 25 kilometers following Conley (1999). In 1800-1859, large and small effects differ at the 90% level. In 1860-99, they differ at the 99% level.

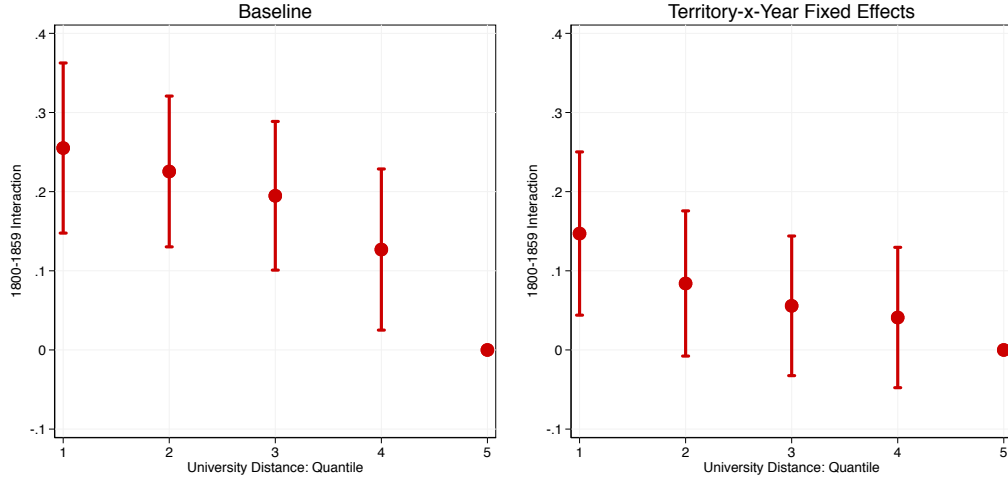
between an indicator for the 1800-1859 period and indicators for distance quintiles. Panel A corresponds to our baseline model (Table 2, column 1) and shows the post-1800 shift in manufacturing declined in distance.³⁴ We observe a similar, but muted pattern when we study effects within territories (Panel B corresponds to Table 2, column 5). This evidence indicates that the “close” and “far” heuristic reflects an underlying spatial gradient.

In fact, analysis of the relationship between manufacturing and linear distance to a university in kilometers supports our baseline estimates. We find a 60 kilometer reduction in distance, equal to median distance, is associated with a 0.13 increase in the count of manufacturing events 1800-1859, which is similar to Figure 4 (Panel A). See Appendix B.

It is also natural to question whether more global measures of university proximity predict industry. We find our estimate holds conditional on distance weighted exposure to all universities and that measures of overall exposure have no significant relationship to

³⁴Mean distance to a university for quantiles 1, 2, 3, 4, and 5 are: 23, 45, 62, 82 and 132 km, respectively.

Figure 6: Distance to a University and Shifts in Manufacturing



Regression estimates in which the outcome is manufacturing events in a city-period. Figure plots estimates on interactions between an indicator for the period 1800-1859 and for a given city’s distance quintile (1 closest, 5 farthest). Left panel corresponds to Table 2, Panel A column 1 (baseline estimate: 0.14). Right panel corresponds to Table 2, Panel A column 5 (fixed effects estimate: 0.07). Estimates include interactions between indicators for distance quantiles and the 1860-1899 period and city fixed effects. Left panel includes year effects. Conley (1999) standard errors allow for arbitrary spatial correlation within 25 kilometers.

industrial activity conditional on our (nearest) university effect (Appendix ??).³⁵

G. Testing for Pre-Trends. While our analysis shows that cities near universities enjoyed no positive pre-trends in manufacturing across the late 1700s, a natural question is whether pre-trends in core pre-industrial outcomes were also similar, including over longer time horizons. City construction is a core indicator of pre-industrial development and data on major projects are consistently observed across all cities in our dataset over longer time horizons (Cantoni, Dittmar, and Yuchtman 2018). We therefore test whether cities near universities enjoyed any differential pre-trend in construction in a fixed effects regression model. Table 4 shows that there are no significant differences in pre-trends. Appendix B shows there are no differences in the level of construction before 1800 and provides details.

5 High and Low Knowledge Manufacturing

Theory and history motivate our second testable hypothesis: that the economic shifts towards universities were most pronounced in knowledge intensive industries.

³⁵We also find that cities close to more than one university had no significant manufacturing advantage after 1800 over cities near just one. Results hold considering universities close to but outside our study area.

Table 4: Test for Pre-Trends in Urban Construction

	(1)	(2)	(3)	(4)
	Outcome: Urban Construction Projects			
	1400-1799	1500-1799	1600-1799	1700-1799
University \times Trend	-0.002 (0.009)	0.004 (0.013)	-0.011 (0.020)	0.018 (0.058)
City & Time FE	Yes	Yes	Yes	Yes
Observations	44820	33615	22410	11205
Mean Outcome	0.286	0.317	0.3575	0.411

This table reports panel regression estimates examining the number of major construction events in a city-period, measured as a 20-year period. “University” is an indicator for cities below median distance to a university in the 1800s and “Trend” is a linear time trend measured in 100-year units. Data on construction are from [Cantoni, Dittmar, and Yuchtman \(2018\)](#) and [Keyser \(1939-1974\)](#). Standard errors are estimated allowing for arbitrary spatial correlation within 25 kilometers following the methodology of [Conley \(1999\)](#).

To test this hypothesis, we study the relationship between universities and knowledge intensive manufacturing. We measure industries as more or less knowledge intensive using our data on discovery. We classify all practical inventions in our data on discoveries by (1) the industry using the invention and (2) whether or not the inventor was university educated.³⁶ We define “high knowledge” industries as those in which university educated inventors account for 50% of inventions 1760-1860.³⁷

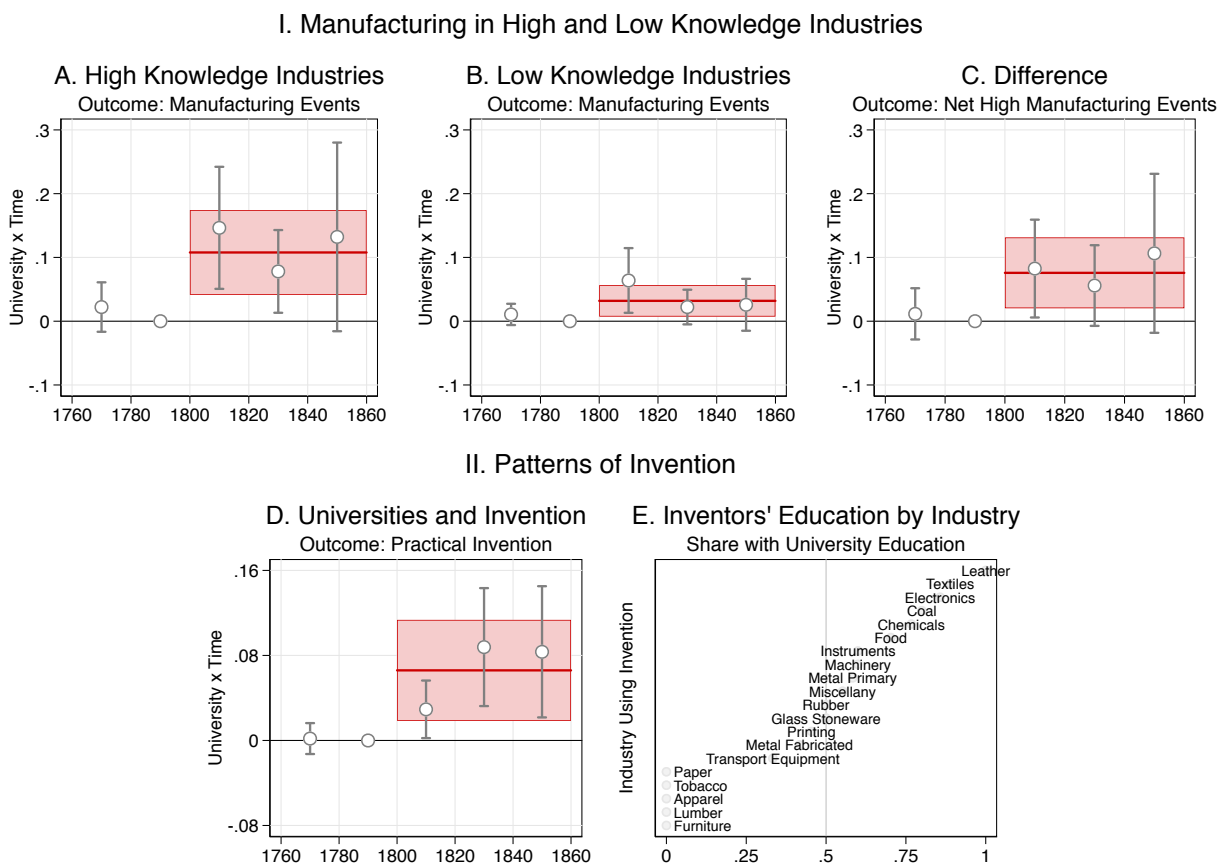
We extend our baseline analysis to study how universities were associated with shifts in manufacturing in higher and lower knowledge industries. We examine three manufacturing outcomes: high knowledge manufacturing; low knowledge manufacturing; and net high knowledge manufacturing, defined as the difference between high and low knowledge manufacturing. We also directly test whether practical inventions with industrial applications shifted spatially towards cities near universities in our panel data after 1800.

Figure 7 presents our findings on the relationship between universities and knowledge intensive manufacturing. Panel I shows that universities were associated with significant increases in manufacturing in high knowledge industries after 1800 (graph A). We observe smaller positive shifts in low knowledge manufacturing that decay over time (graph B). We

³⁶Here we distinguish between purely scientific discoveries and practical inventions, which have industrial applications, discussed in Section 3.

³⁷Practical inventions and manufacturing activities are classified at the two-digit SIC level. Inventions are classified by the industry using them. Thus chemical dyes are classified as used in the textile industry. See Section 3. Our findings below are robust to alternate categorizations of “high” and “low” knowledge industries, including when we classify all industries with university-educated inventors as high knowledge.

Figure 7: Universities and the Knowledge Intensity of Manufacturing



Panel I presents regression estimates examining manufacturing 1760-1859. The outcomes are counts of manufacturing events in city-periods: (A) in “High Knowledge” industries; (B) in “Low Knowledge” industries; and (C) net high knowledge manufacturing. Each graph presents estimates from two regressions. The first estimates the relationship between manufacturing and interactions between university exposure and time fixed effects, relative to the 1780-1799 reference period. The second estimates the relationship between manufacturing and an interaction between university exposure and an indicator for the post-1800 period. University exposure is measured with an indicator for cities close to universities in the 1800s. Graphs present 95% confidence intervals estimated using standard errors allow for spatial correlation over 25 km following [Conley \(1999\)](#). Panel II presents evidence on practical invention 1760-1859. Graph D presents regression estimates of the relationship between practical invention and university exposure. The outcome is the number of practical inventions in a city-period. The estimating models and confidence intervals are as in Panel I. Graph E shows the variation across industries in the share of inventions made by university educated inventors, which is used to classify industries as high or low knowledge in the analyses in Panel I.

also find that university exposure positively predicts the difference or wedge in the expansion of high and low knowledge manufacturing after 1800 (graph C). We observe no pre-trends in high knowledge manufacturing towards universities before the post-1800 shifts.

Panel II clarifies the underlying pattern of invention. Our regression estimates document

that cities near universities had no advantages in practical invention before 1800 and that invention shifted significantly towards universities after 1800 (Graph D). This connects back to the motivation for our study, our finding that a broad measure of science and discovery expanded near universities after 1800 (Figure 1). We now formally confirm that universities were associated with a differential expansion of economically useful knowledge in the early 1800s. Graph E shows the variation across industries in the share of inventions by university educated inventors, which we use to classify industries as “high” or “low” knowledge.

To interpret the estimates in Figure 7 several observations are important. First, the differential shift towards universities in high knowledge manufacturing may reflect supply and demand side dynamics. In particular, the shifts in manufacturing that we observe are likely to reflect how universities and university-educated inventors were differentially able to respond to economic incentives after the shocks of the late 1700s. Indeed, the inventions we study and use to classify industries are themselves, in part, endogenous outcomes in this larger post-shock context. Here the causal process that we study has parallels with the economic role of universities in the United States. [Rosenberg \(2000\)](#) observes that the political shock of WWII promoted science and technology in US universities and thus made it possible for universities to respond to demand in new ways as conduits for induced technological change. In Germany, political shocks similarly promoted science in the universities in the early 1800s, thereby enabling universities to respond to demand in new ways.³⁸

Second, our measure of knowledge intensity based on the pattern of invention may proxy for a broader set of knowledge-related spillovers from universities. Historical evidence indicates that universities contributed directly to the transmission of knowledge about best practices and to the training of mechanics starting in the early 1800s ([Ziche 2001](#)). Universities were thus likely to increase the local flow of small “tweaking” improvements in products and processes that are not observed in our data on major inventions. The observed shifts in high knowledge manufacturing industries can be expected to also reflect these processes, which involved both knowledge and human capital.

³⁸There are contrasts between U.S. universities in the 1900s and German universities in the 1800s. The pro-science shift in U.S. universities coincided with a major expansion of state financial support. German universities in the 19th century delivered remarkable scientific and technological advances on modest budgets, but research funding requirements in the 19th century were comparatively modest ([McClelland 2008](#)).

6 Technological Change and the Quality of Innovation

Our central claim is that the profound pro-science shift in German universities in the early 1800s drove economic development. To further assess this claim, we test our third and fourth hypotheses: that universities promoted both significant technological change in manufacturing and the quality of industrial innovation. To test these hypotheses, we expand our analysis beyond the evidence in the *Deutsches Städtebuch* both out of necessity and to document how the economic process is observed in interlocking bodies of independent data.

To study the pattern of technological change, we examine establishment-level data on a key dimension of technological change in the early 1800s, the adoption of mechanized production techniques. To study the quality of industrial innovation, we examine evidence on competitive awards won by German firms exhibiting products and process technologies at the first World’s Fair, the Crystal Palace Exhibition of 1851.

6.1 Technological Change

It is natural to wonder whether universities were associated with the adoption of *advanced* technology, given the central role of technological change in the industrialization process (Landes 1969). The mechanization of manufacturing was one of the most fundamental technological advances in our period. However, the *Deutsches Städtebuch* does not provide systematic information or clear indications on the technology used in manufacturing.³⁹

To study the relationship between universities and technological change we collect detailed information on the technologies used by individual firms. We examine data gathered by Forberger (1982), which provide virtually comprehensive evidence on manufacturing establishments in Saxony. These data enable us to study, “factories and workshops on the path to manufacturing in the first phase of the Industrial Revolution (1800-1830)” (Forberger 1982; Bd. 1, p. 509 – our translation).⁴⁰ Over the period covered by the data, Saxony emerged as Germany’s leading industrial region (Tilly and Kopsidis 2020; Pollard 1981). The first mechanized textile plant was established in Saxony in 1799-1800 (Meerwein 1914,

³⁹There is significant ambiguity in the historical designations used to describe manufacturing enterprises themselves. For example, the words *Fabrik* and *Manufaktur* do not uniformly map onto “factory” and (pre- or proto-industrial) “manufactory,” respectively. See, for example, Freudenberger and Redlich (1964).

⁴⁰In the original, Forberger (1982) writes: “Fabriken und der auf dem Wege zur fabrikatorischen Fertigung befindlichen Werkstätten in der ersten Phase der Industriellen Revolution (1800-1830)...”

p. 20; see also [Pollard 1981](#)). Mechanization then diffused rapidly. Factories in Saxony accounted for 14% of spindles installed in Germany textiles in 1800, 52% of spindles in 1810, and over 72% in 1815 ([Appendix D](#); [Kirchhain 1973](#); [Forberger 1982](#)).

To document the pattern of mechanization, we classify factories as mechanized or not. We classify 233 factories established in the early 1800s in cities in Saxony, using the categorization of factories (*Art der Fabrik*) provided by [Forberger \(1982\)](#). For example, “factory cotton machine spinning” (*Baumwollmaschinespinnerei*) is *mechanized* and “cotton spinning” (*Baumwollspinnerei*) is *not mechanized*. We note that our classification provides a *proxy* measure of technology choice, as some establishments combined mechanized and non-mechanized production processes. [Appendix A](#) provides details on the data.

We find that mechanized manufacturing concentrated in cities closer to universities in the early 1800s, consistent with our hypothesis. [Table 5](#) presents cross-sectional regression estimates examining manufacturing across cities in Saxony closer to and farther from a university. We observe a significantly higher number of mechanized factories in cities close to universities (column 1). This relationship remains large and statistically significant when we control flexibly for pre-1800 manufacturing period-by-period to absorb underlying pre-trends and shifts (column 2). In contrast, we find a weaker and insignificant relationship between universities and other, non-mechanized manufactories (columns 3 and 4). In cities with manufacturing in the 1800-1830 period, we find that share of firms adopting mechanized technologies was higher in cities closer to universities (columns 5 and 6). These findings are not driven by unusual cities such as Chemnitz, and hold when we allow for arbitrary spatial correlation or study rural manufacturing. We document these points in [Appendix D](#).

To interpret this evidence several observations are important. First, when we examine the evidence on manufacturing from the *Städtebuch* we find similar shifts towards universities in Saxony and other regions (see [Appendix D](#)), but the pattern of mechanization in Saxony may be in part region specific. Second, the larger impact of mechanization in the early 1800s unfolded gradually and via indirect channels, including the development of mechanics’ workshops ([Wolff 1979](#)). Third, while Saxony was a leading industrial region within Germany, the factory system diffused more slowly in Saxony than in industrial regions of England, which points to the significance of a range of forces shaping industrialization.

Table 5: Universities and Mechanization

	(1)	(2)	(3)	(4)	(5)	(6)
	Number of Firms Mechanized		Number of Firms Other		Share of Firms Mechanized	
University	1.90*** (0.64)	1.50*** (0.56)	0.55 (0.66)	0.43 (0.64)	0.37** (0.17)	0.35* (0.18)
Past Manufacturing by Period		Yes		Yes		Yes
Observations	164	164	164	164	38	38
Mean	1.17	1.17	0.25	0.25	0.82	0.82

This table reports regression estimates examining the number of firms and mechanization of establishments set up in cities in Saxony between 1800 and 1830. “University” is an indicator for cities below median distance to a university. “Manufacturing 1750-99” and “Manufacturing 1700-49” measure the number of manufacturing establishments in a city in these periods. “Manufacturing pre-1700” measures manufacturing before 1700. “Past Manufacturing by Period” indicates models which control independently for the number of manufacturing plants established: before 1700; 1700-1749; and 1750-1799. The outcome in columns 1 and 2 is the number of firms in a city using mechanized technology. The outcome in columns 3 and 4 is the number of firms using non-mechanized technology. These regressions are estimated across 164 cities in Saxony with negative binomial regressions. The outcome in columns 5 and 6 is the share of firms in a given city using mechanized technology, estimated with OLS, for the 38 cities with manufacturing establishments. Heteroskedasticity robust standard errors in parentheses. Statistical significance at the 90, 95, and 99 percent confidence level denoted “*”, “**”, and “***”, respectively. Appendix D reports Conley (1999) standard errors. Data are coded from Forberger (1982; 1958).

6.2 The Quality of Innovation

We now test our fourth hypothesis, that universities fostered high quality innovations that took German industry towards or pushed out the world technology frontier.

To study the quality of innovation within Germany, we examine evidence on exhibits and prizes for innovation at the first world’s fair, *The Great Exhibition of the Industry of All Nations* at Crystal Palace, London in 1851. We construct data on innovation in historic Germany from the original exhibition catalogue (Royal Commission 1851), following Moser (2005).⁴¹ We record the cities in which exhibiting firms were based and categorize as “high quality” exhibits that received a Council Medal, Prize Medal, or Honourable Mention. We also record whether the catalogue categorizes high quality exhibits as materials, machinery, or manufactures. Of 1,418 exhibits from German cities, 32% are thus classified as high quality. Across all countries, 30% of exhibits received such awards (Moser 2005; p. 1219).

Within Germany, the quality of innovations at the world’s fair varies with exposure to

⁴¹On the Crystal Palace exhibition as a rich source of evidence on innovation see Moser (2005), who studies how differences in countries’ patent systems explain cross-country differences in exhibits and prizes.

universities. In cities below median distance to a university, 38% of exhibits were high quality. In cities above median distance, 24% were high quality. Within Germany, the 50% of cities thus closer to universities account for 58% of total and 69% of high quality exhibits.⁴²

To formalize these comparisons and test our hypothesis, we estimate cross-sectional regressions of the form: $exhibits_i = \alpha + \beta X_i + u_i$. The outcome is the number of exhibits from city i of a given quality type and X is an indicator for cities closer to universities.

We present our estimates in Table 6. Proximity to a university is associated with 40 percent more total exhibits (0.34 in log counts), however this estimate is only weakly significant (Panel A, column 1). When we disaggregate the data, we find that proximity to universities strongly predicts high quality innovations but does not predict the number of lower quality innovations (columns 3 and 2, respectively). When we disaggregate high quality exhibits by type using the exhibition’s classification, we find that proximity to universities was most strongly associated with award-winning exhibits of machinery and less strongly associated with high quality exhibits of materials and manufactures (columns 4-6).⁴³ These results are consistent with the hypothesis that universities promoted advanced innovation.

The fact that firms in cities close to universities produced internationally competitive innovations suggests that universities were instrumental in the process that took German industry to the world technology frontier. Indeed, we find German cities near universities producing internationally recognized innovations in machines and materials already by the mid-1800s. These findings are consistent with historical evidence indicating that universities were promoting advanced innovation at the beginning of the railroad era and in fields besides chemicals and heavy industry, which are often framed as the key sectors of German industrialization in the late 1800s (see Appendix E).

The Crystal Palace data also confirm and point to the value of our separately collected data on science and invention. Table 6, Panel B shows that the number of Crystal Palace exhibits from a city varies proportionately in the cross-section, with almost unit elasticity, with the measure of scientific and technological discovery we construct in our panel database. Notably our measure is a particularly strong predictor of high quality machine innovations

⁴²While our baseline analysis considers all award-winning exhibits “high quality,” we find an even stronger relationship between universities and awards of Council Medals which were the most competitive prizes.

⁴³In the catalogue, we observe 12 Council Medal awards, 201 Honourable Mentions, and 239 Prize Medals. We find that the relationship between proximity to universities and awards is strongest for Council Medals and positive but weaker for Prize Medals and Honourable mentions.

Table 6: The Quality of Industrial Innovation

	(1)	(2)	(3)	(4)	(5)	(6)
	Outcome: Number of Exhibits by Quality at First World’s Fair					
	Total Exhibits	Low Quality	High Quality	High Quality By Type		
				Material	Machine	Manufacture
<i>A. University Effect</i>						
University	0.34* (0.19)	0.14 (0.14)	0.82** (0.37)	1.03*** (0.31)	1.54*** (0.31)	0.65* (0.35)
<i>B. Scientific and Technological Discoveries</i>						
Discoveries 1830-1849	0.92*** (0.10)	0.96*** (0.14)	0.78*** (0.13)	0.61*** (0.15)	0.97*** (0.25)	0.74*** (0.12)
Observations	2254	2254	2254	2254	2254	2254

This table reports negative binomial regression estimates in which the outcome the number of exhibits from a given German city in the Crystal Palace Exhibition of 1851 ([Royal Commission 1851](#)). “University” is an indicator for cities below median distance to a university. “Discoveries 1830-49” is the number scientific and technological discoveries in a city recorded in [Darmstaedter, du Bois-Reymond, and Schaefer \(1908\)](#). The outcome in column 1 is the total number of exhibits. The outcome in column 2 is the number of “Low Quality” exhibits, defined as those that did not receive awards. The outcomes in columns 3-6 are the number of “High Quality” exhibits, defined as exhibits awarded a Council Medal, Prize Medal, Honourable Mention, or money prize. Robust standard errors clustered by region in the *Städtebuch*.

at Crystal Palace. However, our measure varies across both time and space, and in our data we find that there were no pre-trends towards universities before 1800 and that invention shifts significantly towards universities after 1800 (Figures 1 and 7 above).

7 Conclusion

Universities are widely viewed as core institutions promoting knowledge, industrial innovation, and growth. However, prior research provides limited evidence on the relationship between universities and large scale shifts in economic activity.

Our analysis examines historical evidence from Germany, where the research university first arose, and points to a substantially new view of the industrialization process. We collect and analyze new microdata on science, invention, and manufacturing. In the data, we find that universities drove a pivotal transformation in the German economy starting in the early 1800s. Invention and industry shifted towards universities and accelerated decades before the introduction of railroads and the growth of coal-based industry, which became important in the 1840s. By the mid-1800s, German universities were fostering industrial innovations

that were winning competitive international prizes. The spatial and temporal patterns we uncover indicate that universities played a leading role in the process through which Germany industrialized and embarked on a path towards the world frontier in science-based industry.

The economic process we document reflected political shocks. The French Revolution and Napoleonic invasion led to cultural and institutional changes and reshaped German universities, promoting science and ultimately a model of the university as a center of research that has since diffused internationally. German history thus also provides a model of how political and cultural change that shifts the orientation of higher education towards science and technology can shape development.

While we trace these dynamics over the 1800s, the convulsions in German society in the 20th century – resulting from war, inflation, and the rise of Fascism – point to the potential fragility of science-based growth and to the underlying importance of the political economy environment in the process we study. We focus on the period before Fascist politics and war delivered lasting negative shocks to German universities ([Waldinger 2016](#)). Both the positive economic shifts that we document and these later developments reflect an important instance of a transition to modern growth without democratization.

References

- Acemoglu, Daron, Davide Cantoni, Simon Johnson, and James A. Robinson. 2011. “The Consequences of Radical Reform: The French Revolution.” *American Economic Review* 101 (7):3286–3307.
- Aghion, Philippe. and Peter. Howitt. 1998. *Endogenous Growth Theory*. Cambridge: MIT Press.
- Andrews, Michael. 2022. “How Do Institutions of Higher Education Affect Local Invention? Evidence from the Establishment of U.S. Colleges.” *American Economic Journal: Economic Policy* (forthcoming).
- Arnold, Matthew. 1868. *Schools and Universities on the Continent*. London: MacMillan.
- Asch, Kristine. 2005. *The 1:5 Million International Geological Map for Europe and Adjacent Areas*. Hannover: Die Bundesanstalt für Geowissenschaften und Rohstoffe (BGR).
- Audretsch, David B. and Maryann P. Feldman. 1996. “R&D Spillovers and the Geography of Innovation and Production.” *The American Economic Review* 86 (3):630–640.
- . 2004. “Knowledge Spillovers and the Geography of Innovation.” In *Cities and Geography, Handbook of Regional and Urban Economics*, vol. 4, edited by J. Vernon Henderson and Jacques-François Thisse. Elsevier, 2713–2739.
- Becker, Sascha O., Francesco Cinnirella, Erik Hornung, and Ludger Woessmann. 2014. “iPEHD—The ifo Prussian Economic History Database.” *Historical Methods: A Journal of Quantitative and Interdisciplinary History* 47 (2):57–66.
- Becker, Sascha O., Erik Hornung, and Ludger Woessmann. 2011. “Education and Catch-up in the Industrial Revolution.” *American Economic Journal: Macroeconomics* 3 (1):92–126.
- Becker, Sascha O. and Ludger Woessmann. 2009. “Was Weber Wrong? A Human Capital Theory of Protestant Economic History.” *Quarterly Journal of Economics* 124 (2):531–596.
- Bertrand, Marianne, Esther Duflo, and Sendhil Mullainathan. 2004. “How Much Should We Trust Differences-in-Differences Estimates?” *The Quarterly Journal of Economics* 119 (1):249–275.
- Blackbourn, David. 2003. *History of Germany 1780-1918: The Long Nineteenth Century*. Blackwell Classic Histories of Europe. Oxford: Blackwell.
- Blackbourn, David and Geoff Eley. 1984. *The Peculiarities of German History: Bourgeois Society and Politics in Nineteenth Century Germany*. Oxford: Oxford University Press.
- Braun, Karl. 1860. *Gewerbefreiheit und Freizügigkeit durch ganz Deutschland*. Frankfurt: Sauerlaender Verlag.
- Broadberry, Stephen and Carsten Burhop. 2010. “Real Wages and Labor Productivity in Britain and Germany, 1871–1938: A Unified Approach to the International Comparison of Living Standards.” *The Journal of Economic History* 70 (2):400–427.
- Böhme, Ernst and Rudolf Vierhaus. 2002. *Göttingen: Geschichte einer Universitätsstadt: Band 2*. Göttingen: Vandenhoeck und Ruprecht.
- Cantoni, Davide, Jeremiah Dittmar, and Noam Yuchtman. 2018. “Religious Competition and Reallocation: the Political Economy of Secularization in the Protestant Reformation*.” *The Quarterly Journal of Economics* 133 (4):2037–2096.
- Cantoni, Davide and Noam Yuchtman. 2014. “Medieval Universities, Legal Institutions, and the Commercial Revolution.” *Quarterly Journal of Economics* 129 (2):823–887.

- Cinnirella, Francesco, Erik Hornung, and Julius Koschnick. 2022. “Flow of Ideas: Economic Societies and the Rise of Useful Knowledge.” CESifo Working Paper 9836.
- Conley, T.G. 1999. “GMM estimation with cross sectional dependence.” *Journal of Econometrics* 92 (1):1–45.
- Crouzet, François. 1964. “Wars, Blockade, and Economic Change in Europe, 1792-1815.” *The Journal of Economic History* 24 (4):567–588.
- Darmstaedter, Ludwig and René du Bois-Reymond. 1904. *4000 Jahre Pionier-Arbeit in den Exacten Wissenschaften*. Berlin: J.A. Stargart.
- Darmstaedter, Ludwig, René du Bois-Reymond, and Carl Schaefer. 1908. *Handbuch zur Geschichte der Naturwissenschaften und der Technik*. Berlin: Springer.
- Davidson, Neil. 2012. *How Revolutionary Were the Bourgeois Revolutions?* Chicago: Haymarket.
- de la Croix, David, Frédéric Docquier, Alice Fabre, and Robert Stelter. 2022. “The Academic Market and the Rise of Universities in Medieval and Early Modern Europe (1000-1800).” LISER Working Paper 2022-04.
- Dieterici, Carl Friedrich Wilhelm. 1836. *Geschichtliche und statistische Nachrichten über die Universitäten im preußischen Staate*. Berlin: Duncker & Humblot.
- Dittmar, Jeremiah. 2019. “Economic Origins of Modern Science.” Working paper, London School of Economics.
- Donges, Alexander and Felix Selgert. 2019. “Do Legal Differences Matter? A Comparison of German Patent Law Regimes before 1877.” *Jahrbuch für Wirtschaftsgeschichte* 60 (1):57–92.
- Engelsing, Rolf. 1968. *Kleine Wirtschafts und Sozialgeschichte Deutschlands*. Bremen: Schmalfeldt.
- Eulenburg, Franz. 1904. *Die Frequenz der deutschen Universitäten von ihrer Gründung bis zur Gegenwart*. Leipzig: Teubner.
- Foray, Dominique and Francesco Lissoni. 2010. “Chapter 6 - University Research and Public–Private Interaction.” In *Handbook of The Economics of Innovation, Vol. 1*, edited by Bronwyn H. Hall and Nathan Rosenberg. North-Holland, 275 – 314.
- Forberger, Rudolf. 1958. *Die Manufaktur in Sachsen vom Ende des 16. bis zum Anfang des 19. Jahrhunderts*. Berlin: Akademie-Verlag.
- . 1982. *Die Industrielle Revolution in Sachsen 1800-1861*. Berlin: Akademie-Verlag.
- Fremdling, Rainer. 1977. “Railroads and German Economic Growth: A Leading Sector Analysis with a Comparison to the United States and Great Britain.” *The Journal of Economic History* 37 (3):583–604.
- Fremdling, Rainer and Gerd Hohorst. 1979. “Marktintegration der preußischen Wirtschaft im 19. Jahrhundert: Skizze eines Forschungsansatzes zur Fluktuation der Roggenpreise zwischen 1821 und 1865.” In *Industrialisierung und Raum: Studien zur regionalen Differenzierung im Deutschland des 19. Jahrhunderts*, edited by Rainer Fremdling and Richard Tilly. Stuttgart: Klett-Cotta.
- Freudenberger, Herman and Fritz Redlich. 1964. “The Industrial Development of Europe: Reality, Symbols, Images.” *Kyklos* 17 (3):372–400.
- Gerschenkron, Alexander. 1962. *Economic Backwardness In Historical Perspective-A Book of Essays*. Cambridge: Harvard University Press.

- Guinnane, Timothy W. 2002. “Delegated Monitors, Large and Small: Germany’s Banking System, 1800-1914.” *Journal of Economic Literature* 40 (1):73–124.
- Henderson, W. O. 1956. “The Genesis of the Industrial Revolution in France and Germany in the 18th Century.” *Kyklos* 9 (2):190–207.
- Hermelink, Heinrich and Siegfried A. Kaehler. 1927. *Die Philipps-Universität zu Marburg, 1527-1927: fünf kapitel aus ihrer geschichte*. Marburg: N.G. Elwert.
- Hinz, Gerhard. 1961. *Aus der Geschichte der Universität Heidelberg und ihrer Fakultäten: 1386 - 1961*. Heidelberg: Ruperto Carola.
- Hoffmann, Walther. 1963. “The Take-Off in Germany.” In *The Economics of Take-Off Into Sustained Growth*, edited by W.W. Rostow. New York: MacMillan.
- Hornung, Erik. 2014. “Immigration and the Diffusion of Technology: The Huguenot Diaspora in Prussia.” *American Economic Review* 104 (1):84–122.
- . 2015. “Railroads and Economic Growth in Prussia.” *Journal of the European Economic Association* 13 (4):699–736.
- Jaffe, Adam B. 1989. “Real Effects of Academic Research.” *The American Economic Review* 79:957–970.
- Juhász, Réka. 2018. “Temporary Protection and Technology Adoption: Evidence from the Napoleonic Blockade.” *American Economic Review* 108 (11):3339–76.
- Kant, Immanuel. 1987 [1790]. *Critique of Judgement*. Indianapolis: Hackett.
- Kantor, Shawn and Alexander Whalley. 2014. “Knowledge Spillovers from Research Universities: Evidence from Endowment Value Shocks.” *Review of Economics & Statistics* 96 (1):171 – 188.
- . 2019. “Research Proximity and Productivity: Long-Term Evidence from Agriculture.” *Journal of Political Economy* 127 (2):819–854.
- Kaufhold, Von Karl Heinrich. 1986. “Gewerblandschaften in der Frühen Neuzeit (1650-1800).” In *Gewerbe- und Industrielandschaften vom Spätmittelalter bis ins 20. Jahrhundert*, edited by Hans Pohl. Stuttgart: Franz Steiner Verlag.
- Keyser, Erich. 1939-1974. *Deutsches Städtebuch*. Stuttgart: Kohlhammer.
- Kindleberger, Charles P. 1975. “Germany’s Overtaking of England, 1806–1914 Part II.” *Weltwirtschaftliches Archiv* 111 (3):477–504.
- Kirchhain, Günter. 1973. *Das Wachstum der deutschen Baumwollindustrie im 19. Jahrhundert: eine historische Modellstudie zur empirischen Wachstumsforschung*. Münster: Westfälische Wilhelms-Universität, Münster.
- König, Albin. 1899. *Die sächsische Baumwollenindustrie: am Ende des vorigen Jahrhunderts und während der Kontinentalsperre*. Leipzig: Druck und Verlag von B.G. Teubner.
- Kopsidis, Michael and Daniel W. Bromley. 2016. “The French revolution and German industrialization: dubious models and doubtful causality.” *Journal of Institutional Economics* 12 (1):161–190.
- Krause, Konrad. 2003. *Alma mater Lipsiensis: Geschichte der Universität Leipzig von 1409 bis zur Gegenwart*. Leipzig: Leipziger Universitätsverlag.
- Kreidte, Peter, Hans Medick, and Jürgen Schlumbohm. 1977. *Industrialisierung vor der Industrialisierung: Gewerbliche Warenproduktion auf dem Land in der Formationsperiode des Kapitalismus*. Göttingen: Vandenhoeck und Ruprecht.

- Kuczynski, Jürgen. 1961. *Die Geschichte der Lage der Arbeiter unter dem Kapitalismus, Bd. 1: Darstellung der Lage der Arbeiter in Deutschland von 1789 bis 1849*. Berlin: Akademie-Verlag.
- Kunz, Alexander and Alexander Zipf. 2008. "HGIS Germany: Historical information system of the German states, 1820 to 1914."
- Kuznets, Simon. 1968. *Toward a Theory of Economic Growth, With "Reflections on the Economic Growth of Modern Nations"*. New York: W.W. Norton.
- Landes, David S. 1969. *The Unbound Prometheus: Technical Change and Industrial Development in Western Europe from 1750 to Present*. Cambridge: Cambridge University Press.
- Lenz, Max. 1910. *Geschichte der Königlichen Friedrichs-Wilhelms-Universität zu Berlin*. Halle an der Saale: Verlag der Buchhandlung des Waisenhauses.
- Lundgreen, Peter. 1975. "Industrialization and the Educational Formation of Manpower in Germany." *Journal of Social History* 9 (1):64–80.
- Marcuse, Herbert. 1960. *Reason and Revolution*. Boston: Beacon.
- Marino, Luigi. 1995. *Praeceptores Germaniae: Göttingen 1770-1820*. Göttingen: Vandenhoeck & Ruprecht.
- Marshall, Alfred. 1920. *Principles of Economics*. London: MacMillan.
- Martin, Bernd. 2007. *550 Jahre Albert-Ludwigs-Universität Freiburg, Band 3*. Freiburg im Breisgau: Verlag Karl Alber.
- Marx, Karl. 1975 [1842]. "The Philosophical Manifesto of the Historical School of Law." In *Collected Writings, Volume 2*, edited by Karl Marx and Friedrich Engels. Moscow: Progress Publishers.
- McClelland, Charles. 2008. *State, Society and University in Germany 1700-1914*. Cambridge: Cambridge University Press.
- . 2019. "The Emergence of Modern Higher Education: The German University and Its Influence." In *Handbook of the History of Education*, edited by John L. Rury and Eileen H. Tamura. Oxford: Oxford University Press.
- Meerwein, Georg. 1914. *Die Entwicklung der Chemnitzer bezw. sächsischen Baumwollspinnerei von 1789-1879*. Berlin: Emil Ebering.
- Meisenzahl, Ralf. 2015. "How Britain Lost its Competitive Edge: Competence in the Second Industrial Revolution." In *Institutions, Innovation, and Industrialization: Essay in Economic History and Development*, edited by Avner Greif, Lynne Kiesling, and John V.C. Nye. Princeton: Princeton University Press.
- Mitch, David. 1999. "The Role of Education and Skill in the British Industrial Revolution." In *The British Industrial Revolution: An Economic Perspective*, edited by Joel Mokyr. Oxon: Taylor & Francis.
- Mokyr, Joel. 2005. "The Intellectual Origins of Modern Economic Growth." *The Journal of Economic History* 65 (2):285–351.
- . 2016. *A Culture of Growth*. Princeton: Princeton University Press.
- Moser, Petra. 2005. "How Do Patent Laws Influence Innovation? Evidence from Nineteenth-Century World's Fairs." *American Economic Review* 95 (4):1214–1236.
- Mottek, Hans. 1960. "Einleitende Bemerkungen: Zum Verlauf und zu einigen Hauptproblemender industriellen Revolution in Deutschland." In *Studien zur Geschichte der industriellen Revolution in Deutschland*, edited by Hans Mottek. Berlin: Akademie Verlag, 18–59.

- Nadbyl, Bernard. 1861. *Chronik und Statistik der königlichen Universität zu Breslau*. Breslau: Druck der königlichen Universität.
- Nelson, Richard R. and Edmund S. Phelps. 1966. "Investment in Humans, Technological Diffusion, and Economic Growth." *The American Economic Review* 56 (1/2):69–75.
- Ogilvie, Sheilagh. 1996. "The Beginnings of Industrialization." In *Germany: A New Social and Economic History (Volume 2: 1630-1800)*, edited by Robert W. Scribner and Sheilagh C. Ogilvie. London: Arnold, 263–308.
- Palmer, R.R. 2014. *The Age of Democratic Revolution: A Political History of Europe and America 1760-1800*. Princeton: Princeton University Press.
- Pierenkemper, Toni and Richard Tilly. 2004. *The German Economy During the Nineteenth Century*. New York: Berghahn Books.
- Pollard, Sidney. 1981. *Peaceful Conquest: The Industrialization of Europe 1760-1970*. Oxford: Oxford University Press.
- . 1990. *Typology of Industrialization Processes in the Nineteenth Century*. Chur: Harwood.
- Prutz, Hans. 1894. *Die Königlische Albertus-Universität zu Königsberg i. Pr. im neunzehnten Jahrhundert*. Königsberg: Hartungsche Verlagsdruckerei.
- Rang-Dudzik, B. 1981. "Qualitative and Quantitative Aspects of Curricula in Prussian Grammar Schools During the Late 18th and Early 19th Centuries and Their Relation to the Development of the Sciences." In *Epistemological and Social Problems of the Sciences in the Early Nineteenth Century*, edited by H.N. Janke and M. Otte. Dordrecht: D. Reidel.
- Romer, Paul M. 1994. "The Origins of Endogenous Growth." *Journal of Economic Perspectives* 8 (1):3–22.
- Rosenberg, Nathan. 1976. *Perspectives on Technology*. Cambridge: Cambridge University Press.
- . 2000. *Schumpeter and the Endogeneity of Technology*. London: Routledge.
- Royal Commission. 1851. *Official descriptive and illustrated catalogue of the Great exhibition of the works of industry of all nations, 1851*. London: W. Clowes and Sons.
- Rüegg, Walter. 2004a. "European Universities and Similar Institutions in Existence Between 1812 and the End of 1944." In *A History of the University in Europe: Volume III Universities in the Nineteenth and Early Twentieth Centuries*, edited by Walter Rüegg. Cambridge: Cambridge University Press.
- . 2004b. "Themes." In *A History of the University in Europe: Volume III Universities in the Nineteenth and Early Twentieth Centuries*, edited by Walter Rüegg. Cambridge: Cambridge University Press.
- Schlotter, Hans-Günther. 1994. *Die Geschichte der Verfassung und der Fachbereiche der Georg-August-Universität zu Göttingen*. Göttingen: Vandenhoeck & Ruprecht.
- Schumpeter, Joseph A. 1939. *Business Cycles: A Theoretical, Historical, and Statistical Analysis of the Capitalist Process*. New York: McGraw-Hill.
- Schwedt, Georg. 2002. *Liebig und seine Schüler – die neue Schule der Chemie*. Berlin: Springer.
- Segal, Zef. 2018. "The two edged sword: capital cities and the limits to state centralization in mid nineteenth-century Germany." *Journal of Historical Geography* 60:52 – 63.
- Sombart, Werner. 1909. *Die deutsche Volkswirtschaft im neunzehnten Jahrhundert*. Berlin: Bondi.

- Squicciarini, Mara P. and Nico Voigtländer. 2015. “Human Capital and Industrialization: Evidence from the Age of Enlightenment.” *The Quarterly Journal of Economics* 130 (4):1825–1883.
- Streb, Jochen, Jörg Baten, and Shuxi Yin. 2006. “Technological and geographical knowledge spillover in the German empire 1877–1918.” *The Economic History Review* 59 (2):347–373.
- Tilly, Richard. 1991. “Germany.” In *Patterns of European Industrialization: The Nineteenth Century*, edited by Richard Sylla and Gianni Toniolo. London: Routledge, 175–196.
- . 2001. “German economic history and Cliometrics: A selective survey of recent tendencies.” *European Review of Economic History* 5 (2):151–187.
- Tilly, Richard and Michael Kopsidis. 2020. *From Old Regime to Industrial State: A History of German Industrialization from the Eighteenth Century to World War I*. Chicago: University of Chicago Press.
- Tipton, Frank. 1976. *Regional Variations in Economic Development of Germany During the Nineteenth Century*. Middletown: Wesleyan University Press.
- Titze, Hartmut. 1995. *Wachstum und Differenzierung der deutschen Universitäten: 1830-1945*. Göttingen: Vandenhoeck & Ruprecht.
- Turner, R. Steven. 1975. “University Reformers and Professional Scholarship in Germany 1760–1806.” In *The University in Society: Volume II – Europe, Scotland, and the United States from the 16th to the 20th Century*, edited by Lawrence Stone. Princeton: Princeton University Press.
- . 1987. “The Great Transition and the Social Patterns of German Science.” *Minerva* 25 (1/2):56–76.
- Urquiola, Miguel. 2020. *Markets, Minds, and Money: Why America Leads the World in University Research*. Cambridge: Harvard University Press.
- Valero, Anna and John Van Reenen. 2019. “The economic impact of universities: Evidence from across the globe.” *Economics of Education Review* 68:53 – 67.
- Van Bommel, von Bas. 2015. “Between ‘Bildung’ and ‘Wissenschaft’: The 19th-Century German Ideal of Scientific Education.” In *Europäische Geschichte Online*. Mainz: Leibniz-Institut für Europäische Geschichte (IEG), 1–26.
- Waldinger, Fabian. 2016. “Bombs, Brains, and Science: The Role of Human and Physical Capital for the Creation of Scientific Knowledge.” *Review of Economics and Statistics* 98 (5):811–831.
- Weber, Cornelia, Ingeborg Reichle, Elena Semenova, Anja Walther, Oliver Zauzig, and David Ludwig. 2013. “Universitäts-sammlungen in Deutschland: Untersuchungen zu Bestand und Geschichte.” URL <http://www.universitaetssammlungen.de>.
- Whaley, Joachim. 2012. *Germany and the Holy Roman Empire: Volume II: The Peace of Westphalia to the Dissolution of the Reich, 1648-1806*. Oxford: Oxford University Press.
- Wolff, Klaus H. 1979. “Guildmaster into Millhand: The Industrialization of Linen and Cotton in Germany to 1850.” *Textile History* 10 (1):7–74.
- Wrigley, E. A. 1961. *Industrial Growth and Population Change: A Regional Study of the Coalfield Areas of North-west Europe in the Later Nineteenth Century*. Cambridge: Cambridge University.
- Ziche, Paul. 2001. “Die Grenzen Universität: Naturforschende, physikalische und mechanische Aktivitäten in Jena.” In *Die Universität Jena: Tradition und Innovation um 1800*, edited by Gerhard Müller, Klaus. Ries, and Paul Ziche. Stuttgart: Franz Steiner.

Appendices – For Online Publication

A Data

A.1 Sources and summary statistics

Manufacturing. We construct data on city-level manufacturing from the *Deutsches Städtebuch* (Keyser 1939-1974), recording the timing and sector of manufacturing “events” as described in the main text. The *Deutsches Städtebuch* is a historic encyclopedia of settlements in German-speaking Europe that acquired city rights. Our analysis focuses on 2,254 cities examined in Cantoni and Yuchtman (2014), mapped in Figure 3. We examine corroborating evidence on county-level manufacturing from the 1849 Prussian Census from Becker et al. (2014), described in Section A.2 below.

Universities. We construct data on the location and dates of operation of universities from Rüegg (2004a;b).

Schools. We gather evidence on all schools founded in the cities we study from the *Deutsches Städtebuch* (Keyser 1939-1974). Our main analysis focuses on “higher schools,” that is secondary schools including: *Gymnasia*, *Lyzeen* (*Lyzeum*), *Realschulen*, and *Gewerbeschulen* (technical schools). Our findings are robust to extending our analysis to consider, and control for, the potential differential impact of vocational schools, middle schools, and elementary schools as shown in Appendix F.

Railroads. We construct measures of city-level railway connections based on the spatial development of the railroad network, using GIS maps from Kunz and Zipf (2008).

Coal Deposits. We record whether cities are near coal deposits using geological evidence from, “The 1:5 Million International Geological Map for Europe and Adjacent Areas” prepared by Die Bundesanstalt für Geowissenschaften und Rohstoffe (Asch 2005).

Free Enterprise Laws. Territorial-level data on the passage of “free enterprise laws” (*Gewerbefreiheit*) are coded following Acemoglu et al. (2011) and Kopsidis and Bromley (2016). Additional territories are coded based on information in Braun (1860).

Territories. We assign cities to 44 historic territories of the German Union (*Deutscher Bund*), as constituted in 1815.

Scientific and Technological Discovery. We gather evidence on scientific breakthroughs and inventions from [Darmstaedter, du Bois-Reymond, and Schaefer \(1908\)](#). We match inventions and discoveries to town locations by constructing evidence on the lives and employment of inventors from the *Deutsche Biographie*, the *World Biographical Information System* and historical sources. We also construct data on the educational backgrounds of all scientists and inventors, recording whether or not they were university-educated.

Technology Adoption in Saxony. Data on factories, workshops, and the adoption of mechanized production technologies in Saxony between 1800 and 1830 are from [Forberger \(1982\)](#). We rely on [Forberger \(1958\)](#) for evidence on manufacturing in Saxony before 1800.

Exhibits and Prizes at the 1851 World’s Fair. Data on German exhibits at *The Great Exhibition of the Industry of All Nations* at Crystal Palace, London are collected from the original exhibition catalogue ([Royal Commission 1851](#)).

* * *

Table [A1](#) presents summary statistics on the city-level panel dataset we use to examine manufacturing in Sections [4](#) and [5](#). Table [A2](#) presents summary statistics on the database of scientific break-throughs and inventions building on [Darmstaedter, du Bois-Reymond, and Schaefer \(1908\)](#) that we examine in Section [5](#). Table [A3](#) presents summary statistics on the city-level cross-sectional dataset we use to examine technological change in Saxony (Section [6.1](#)). Table [A4](#) presents summary statistics on the cross-sectional city-level dataset on industrial innovations exhibited at the 1851 Crystal Palace exhibition (Section [6.2](#)).

Table [A5](#) provides an illustrative examples of our data building on [Darmstaedter, du Bois-Reymond, and Schaefer \(1908\)](#) that we examine in Section [5](#).

Table A1: Summary Statistics on Manufacturing

	Mean	S. D.
Count Manufacturing	0.271	0.919
Any Manufacturing	0.170	0.428
High Knowledge Manufacturing	0.206	0.729
Low Knowledge Manufacturing	0.065	0.332
University 1845	0.500	0.500
Railroad Connection	0.046	0.209
Free Enterprise Law	0.360	0.480
Early Manufacturing	0.132	0.338
Coal \times Post-1840	0.214	0.410
Coal \times Post-1800	0.357	0.479
Higher School Lead	0.211	0.408
Higher School	0.190	0.392
Higher School Lag	0.148	0.355
Observations	15778	

“Count Manufacturing” is the count of manufacturing events in a city-period of twenty years. “Any Manufacturing” is an indicator for any manufacturing. “University 1845” and “University 1785” are time-invariant indicators for cities that were below median distance to a university active in these decades. “Railroad Connection” is an indicator for railroad connections in a city-period. “Free Enterprise Law” is an indicator for cities in territories that had passed *Gewerbefreiheit* legislation. “Early Manufacturing” is an indicator for the presence of pre-1760 manufacturing in a city. “Coal” is an indicator for cities below median distance to coal deposits. “Higher School” is an indicator for cities in which a higher school was or had been established.

Table A2: Summary Statistics on Knowledge Intensity and Invention

	Mean	S.D.
Scientific Discovery	0.388	0.487
Technological Discovery	0.744	0.436
University Education of Scientist or Inventor	0.801	0.400
Observations	1119	

This table summarizes the data on scientific and technological discovery used to classify manufacturing industries as “High Knowledge” and “Low Knowledge,” based on the educational backgrounds of inventors producing technological discoveries. These data cover the period 1760-1860. The underlying observations are constructed from [Darmstaedter, du Bois-Reymond, and Schaefer \(1908\)](#). Our analysis first determines which individual discoveries were made in the 2,254 cities we study and then classifies observations as indicated in this table. “Scientific Discovery” is an indicator that takes the value of 1 for observations that are or involve basic scientific discoveries. “Technological Discovery” is an indicator for observations that are inventions or innovations with practical applications, including in manufacturing. “University Education of Scientist or Inventor” is an indicator that takes the value of 1 for discoveries where the scientists or inventor has a university education.

Table A3: Summary Statistics on Technology Adoption in Saxony

	Mean	S.D.
Number of Mechanized Firms	1.171	5.356
Number of Non-mechanized Firms	0.250	1.093
Share of Mechanized Firms	0.822	0.315
University	0.500	0.502
Manufacturing pre-1700	0.091	0.493
Manufacturing 1700-1749	0.134	0.622
Manufacturing 1750-1799	0.732	3.161
Observations	164	

This table summarizes the cross-sectional data on the adoption of mechanized technologies 1800-1830 by firms in cities in Saxony. “Number of Mechanized Firms” and “Number of Non-Mechanized Firms” are the number of such firms in a given city 1800-1830, coded as indicated in Table ???. “Share of Mechanized Firms” is the share of firms that are mechanized, which is observed only in cities with any firms. “University” is an indicator for cities below median distance to a university in 1785. “Manufacturing pre-1700,” “Manufacturing 1700-1749,” and “Manufacturing 1750-1799” are the number of manufacturing firms (establishments) observed in these periods. Data on mechanization post-1800 and on pre-1800 manufacturing are from [Forberger \(1982\)](#) and [Forberger \(1958\)](#), respectively.

Table A4: Summary Statistics on Innovations at Crystal Palace in 1851

	Mean	S.D.
Total Number of Exhibits	0.629	5.120
High Quality Exhibits	0.197	1.968
Low Quality Exhibits	0.432	3.468
High Quality in Materials	0.035	0.274
High Quality in Machines	0.023	0.367
High Quality in Manufactures	0.133	1.383
University	0.500	0.500
Scientific and Technological Discoveries 1830-1849	0.116	1.750
Observations	2254	

This table summarizes cross-sectional data on innovations exhibited at *The Great Exhibition of the Industry of All Nations* at Crystal Palace in 1851. “Total Number of Exhibits” is the total number of exhibits at Crystal Palace from a given city. “High Quality Exhibits” is the number of exhibits receiving an award, as described in the text. “Low Quality Exhibits” is the number of exhibits not receiving an award. High quality exhibits in “Materials,” “Machines,” and “Manufactures” are the number of high quality (award-winning) exhibits in each category, as recorded in the original catalogue. These data are coded from [Royal Commission \(1851\)](#). “University” is an indicator for cities below median distance to a university in 1845. “Scientific and Technological Discoveries 1830-1849” is the number of observations in a given city recorded in [Darmstaedter, du Bois-Reymond, and Schaefer \(1908\)](#).

Table A5: Examples of Individual Inventions and Discoveries

Subject Classification	Year	Town	Industry	University	Note
Beet sugar production (<i>Rübenzuckerfabrikation</i>)	1801	Berlin	Food	1	Inventor Franz Karl Achard builds first sugar factory in Konary, Silesia.
Sulfurmilk (<i>Sulfurmilch</i>)	1807	Erfurt	Chemicals	1	Inventor Christian Friedrich Bucholz published 100+ papers on chemicals and production.
Galvanic series (<i>Spannungsreihe der Metalle</i>)	1808	Halle	Metals	1	Galvanic series are used to determine galvanic reaction, the principle upon which batteries are based.
Steel and cast iron production (<i>Stahl- und Flusseisenbereitung</i>)	1811	Essen	Metals	0	Inventor Friedrich Krupp founds the Krupp steel company in same year.
Reproduction of pictorial representation (<i>Reproduktion von bildlichen Darstellungen</i>)	1815	Magdeburg	Printing	0	Significantly reduced costs of reproducing pictures.
Production of artificial mineral waters (<i>Fabrikation der künstlichen Mineralwässer</i>)	1817	Dresden	Food	1	Inventor Friedrich A. A. Struve's business flourished, was knighted for achievements.
Chromium-acid based dyes (<i>Chromsaure Salze zum Färben</i>)	1820	Schneeberg	Textiles	1	Inventor Ernst August Geitner built chemical factory in 1810 and commercialized many inventions.
Chain blower (<i>Kettengebläse mit Wasserhinderung</i>)	1820	Kassel	Mining	0	Inventor Carl Anton Henschel was mostly self-taught and his company Henschel & Sohn produced equipment starting in 1817.
Platin catalysts and lighter (<i>Platinkatalysatoren und -feuerzeug</i>)	1824	Jena	Misc	1	Inventor Johann Wolfgang Döbereiner taught in a colloquium in practical chemistry at the university of Jena in 1820. He was also instrumental in building a sugar factory and a ethanoic acid factory.
Ammonian and ammonium compounds (<i>Ammoniak oder Ammoniumverbindungen</i>)	1828	Giessen	Chemicals	1	The third invention by Justus von Liebig in our data. Liebig owned a private institute for pharmacy and an equipment workshop to supplement his income between 1827 and 1833.
Leukol, rosolic and carboic acid (<i>Leukol, Carbolsäure and Rosolsäure</i>)	1834	Oranienburg	Chemicals	1	Inventor Friedlieb Ferdinand Runge professor of technology in Breslau before leaving academia in 1832 to work as industrial chemist at Chemische Etablissement Dr. Hempel (Chemische Produkten-Fabrik Oranienburg).
Cork borer (<i>Korkbohrer</i>)	1838	Koblenz	Equipment	1	Inventor Karl Friedrich Mohr also co-founded a local chamber of commerce and later invested in the chemical industry.
Self-interrupting pointer telegraph (<i>Zeiger-telegraphen mit Selbstunterbrechung</i>)	1846	Berlin	Equipment	1	This is the first of many inventions by Werner von Siemens in our database.

“Subject Classification” is the hand-coded classification of the subject of the invention and scientific discovery. “Year” is the year of the invention or discovery as per [Darmstaedter, du Bois-Reymond, and Schaefer \(1908\)](#). “Town” is the location of the invention or discovery, coded from historical and biographical sources. “Industry” is our classification of the industry that used the given invention or break-through. “University” column records whether the inventor had a university education.

A.2 Manufacturing in *Städtebuch* and in administrative data

To document the variation in the measure of manufacturing we construct from the *Deutsches Städtebuch*, and to verify what these data capture, we compare them to the first large scale administrative data on manufacturing in Germany, the Prussian census of 1849. We specifically examine how our measure of manufacturing is correlated with county-level data on the number of factories and the number of workers in different types of manufacturing activity in the 1849 census.

We compare our data on manufacturing to the census data on a industry-by-industry basis. We estimate cross-sectional regressions: $man_i^c = \alpha + \beta man_i^s + \epsilon_i$, where man_i^c is manufacturing activity in the 1849 Prussian Census, measured by either the number of factories or by the number of workers in a given two-digit industry in county i . Similarly, man_i^s is the number of manufacturing events in the same industry in county i recorded in the *Städtebuch* between 1820 and 1839.⁴⁴ To estimate these relationships, we aggregate our city-level data to the level of their respective Prussian counties (the mean Prussian county comprises 3.5 *Städtebuch* cities). We aggregate manufacturing events to the industry level, following the two-digit SIC coding for manufacturing activity but combining all metal-related manufacturing in a single industry. We estimate negative binomial regressions.

Table A6 documents the correlation between our measure of manufacturing and the number of factories and workers in a given industry. For most sectors the correlation is highly significant and the estimates are close to, and not statistically different from, unit elasticities. It should be noted, however, that the outcome measures the number of active factories or workers in 1849, whereas our *proxy* measure of manufacturing from the *Städtebuch* measures the opening and, in some cases, the presence of factories in earlier periods. We exclude the 1840s from the *Städtebuch* measure because for some cities data recorded for “the 1840s” in fact reflect the Census itself. By restricting our analysis to factories established in the 20 years before the 1840s, we ensure we do not regress information from the Census on itself, but this also implies that here our measure does not capture variation in industrial activity dating from the 1840s. Of the industries in question, transportation equipment expanded relatively dramatically in the 1840s, with the build out of the railroads, which in

⁴⁴We examine the period before 1840 to capture how the *flows* of plant openings recorded before the 1840s in the *Deutsche Städtebuch* captures the *stock* of factories (and number of workers employed) in the 1840s.

part explains the high elasticity estimate for this industry.

Table A6: Evidence on Manufacturing by Industry

Manufacturing Industry	(1)	(2)	(3)	(4)
	Factories in 1849 Census in Given Industry		Workers in 1849 Census in Given Industry	
	β	Std. Err.	β	Std. Err.
Food	1.01***	(0.30)	1.69***	(0.33)
Tobacco	1.04**	(0.46)	1.50***	(0.53)
Textiles	0.54***	(0.17)	0.94***	(0.24)
Paper	1.18***	(0.40)	1.35**	(0.60)
Chemicals	1.38***	(0.28)	1.42***	(0.34)
Leather	0.51	(0.68)	1.03*	(0.61)
Glass	0.81	(0.73)	0.65	(0.65)
Metals	0.62*	(0.33)	1.09***	(0.32)
Machines	1.90**	(0.95)	1.85**	(0.79)
Transport Equipment	3.43***	(0.47)	3.24***	(0.39)

This table reports regression estimates in which the outcome is either the number of factories (columns 1-2) or the number of workers (columns 3-4) in a given industry and county in the 1849 Prussian census. Each row presents estimates from industry-specific binomial regressions: $man_i^c = \alpha + \beta man_i^s + \epsilon_i$. The outcome is the number of workers or number of factories recorded in 1849 Prussian Census (Becker et al. 2014). The independent variable is the measure of manufacturing events in a given industry recorded in the *Deutsches Städtebuch* (Keyser 1939-1974) from 1820 through 1839. City-level data constructed from Keyser (1939-1974) are aggregated to the county-level for 229 historical Prussian counties within the coverage of the *Deutsches Städtebuch*. Standard errors clustered by administrative district (*Regierungsbezirk*). Statistical significance at the 90, 95, and 99 percent confidence level denoted “*”, “**”, and “***”, respectively.

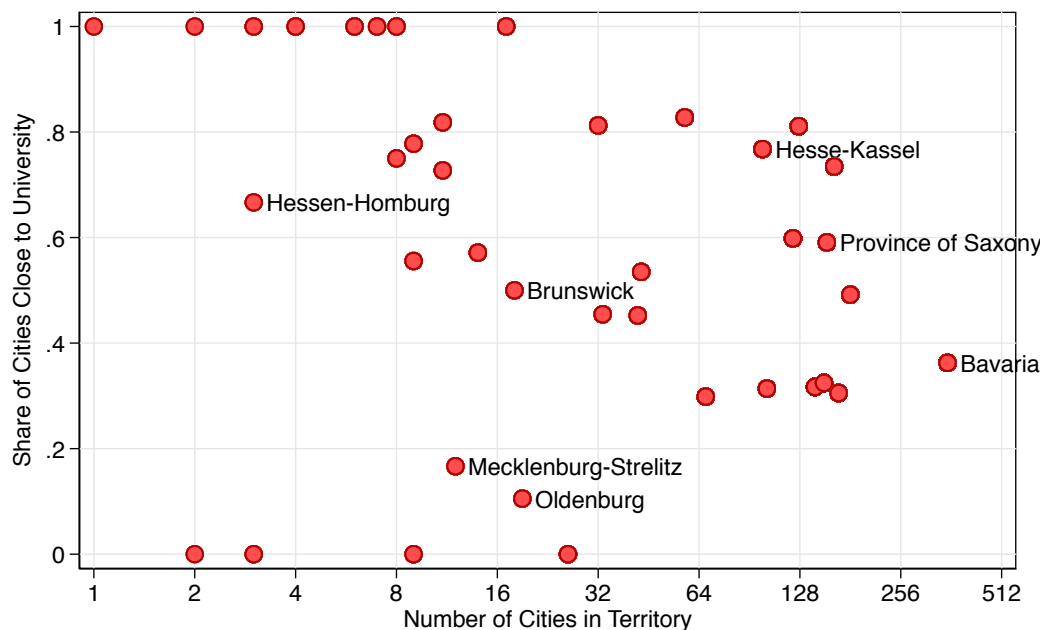
A.3 Territories within historic Germany

Several of our analyses study the relationship between university exposure and manufacturing within territory- \times -time cells (see Table 2 and Table 3). To clarify the variation we study, we present evidence on the within-territory variation.

Figure A1 plots territory-level evidence on the the share of cities close to a university against the number of cities in a given territory.

Table A7 presents evidence on the distribution of cities across territories, and illustrates the within-territory variation in the number cities were located close to and far from universities. Table A7 distinguishes between cities located closer to and farther from universities in the 1800s, defined as being above or below median distance to a university in the 1840s. We note that these territorial definitions are as of 1815. This accounts for the

Figure A1: Variation in University Exposure within Territories



This graph summarizes the variation in university exposure within 44 territories of the German Bund as of 1815. The horizontal axis records the number of cities in a territory. The vertical axis records the share of these cities that were close to universities, defined as below median distance, in the 1800s.

small difference between number of cities in Saxony listed in Table A7 and examined in our analysis of mechanization in Saxony in Table 5.

B Universities and Manufacturing

This appendix provides further analysis on the relationship between universities and manufacturing. In particular, the analysis re-examines how proximity to universities was related to development using a more flexible approach to geographic distance and offers additional evidence relating to the potential endogeneity of university locations.

First, to clarify the pattern of spillovers, we provide further evidence on geographic proximity to universities and the development of manufacturing. We do this by studying the implications of distance both (A) more flexibly and (B) in a linear framework.

Second, we provide evidence on the relationship between new universities – founded in the early 1800s – and the development of manufacturing after 1800. We show that new universities were not associated with any differential shift in manufacturing.

Third, we examine the relationship between manufacturing and proximity to historical

Table A7: Cities and Proximity to Universities by Territory

Territory	Cities by Proximity to University in 1800s		Total Cities
	Number Far From	Number Close To	
Anhalt-Bernburg	2	7	9
Anhalt-Dessau	2	6	8
Anhalt-Köthen	0	4	4
Baden	24	103	127
Bavaria	227	126	353
Brandenburg	102	49	151
Brunswick	9	9	18
Free City	4	5	9
Hannover	70	32	102
Hesse-Darmstadt	10	48	58
Hesse-Kassel	23	76	99
Hessen-Homburg	1	2	3
Hohenzollern-Hechingen	0	1	1
Hohenzollern-Sigmaringen	0	6	6
Lauenburg	3	0	3
Lippe-Detmold	9	0	9
Lübeck	2	0	2
Mark	19	14	33
Mecklenburg-Schwerin	20	23	43
Mecklenburg-Strelitz	10	2	12
Oldenburg	17	2	19
Poland	26	0	26
Pomerania	47	20	67
Province of Saxony	63	91	154
Reuß ältere Linie (Reuß-Greiz)	0	3	3
Reuß-Ebersdorf	0	2	2
Reuß-Gera	0	4	4
Reuß-Lobenstein	0	1	1
Reuß-Schleiz	0	3	3
Rhineland	92	89	181
Sachsen-Coburg-Saalfeld	2	9	11
Sachsen-Gotha-Altenburg	0	17	17
Sachsen-Hildburghausen	0	6	6
Sachsen-Meiningen	0	7	7
Sachsen-Weimar-Eisenach	6	26	32
Saxony	117	50	167
Schaumburg-Lippe	3	0	3
Schleswig-Holstein	23	19	42
Schwarzburg-Rudolstadt	0	8	8
Schwarzburg-Sondershausen	3	8	11
Silesia	91	51	142
Waldeck	6	8	14
Westphalia	49	73	122
Württemberg	45	117	162

universities active in the late 1700s, before the political shocks initiated by the French Revolution. This analysis shows that historical university exposure predicts subsequent manufacturing activity and how the closure of universities attenuates these effects.

Fourth, we use evidence on student enrollment trends as indicators of university quality to examine whether the closure of historic universities was selective. We find that the universities that were closed over the period we study did not exhibit any differential enrollment trends before the political shocks of the late 1700s, which led to the closures.

Fifth, we use data on urban construction to further test whether cities closer to universities enjoyed development advantages before 1800. We test and confirm that university locations were not associated with differences in pre-industrial development, as measured by construction.

Sixth, we examine the relationship between universities and manufacturing controlling for the spatial location of “economic societies” which were established in some cities in the late 1700s to promote the diffusion of knowledge. This analysis shows that our estimated university effects hold controlling for the location of economic societies, which in theory could represent a confounding factor also shaping manufacturing.

B.1 Distance to Universities and Shifts in Manufacturing

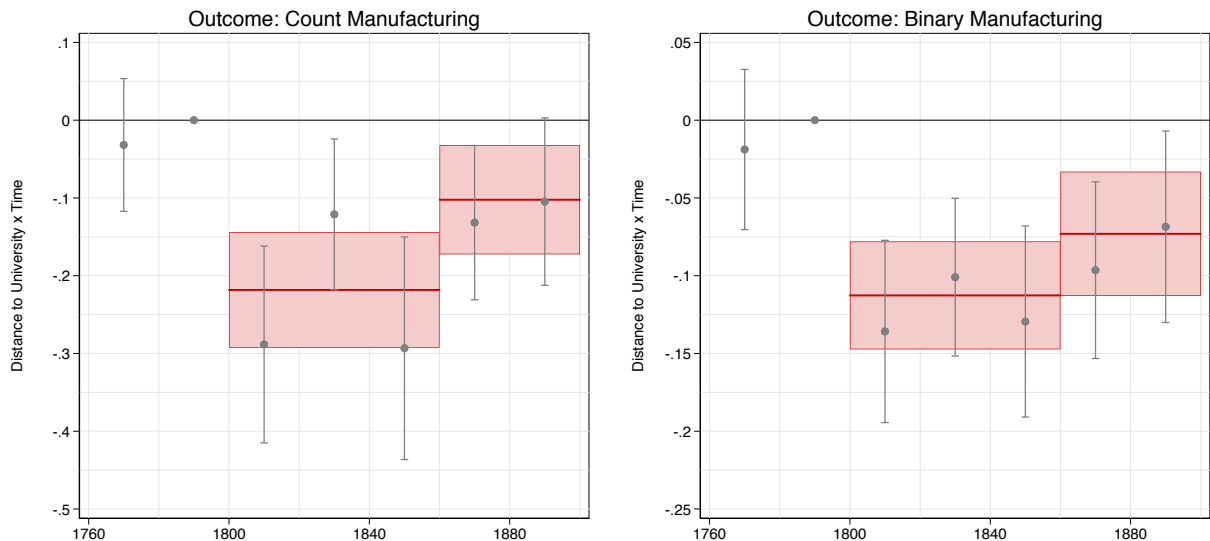
Our baseline analysis draws a binary distinction between cities close to and far from a university. To clarify the underlying pattern of spillovers, it is helpful to consider the role of distance both more flexibly and in a linear framework.

Second, to further clarify the economic process, we examine the relationship between manufacturing and distance to universities measured in kilometers. As in our baseline analysis, we examine interactions between university exposure and time period indicators. We now measure university exposure by the distance to the nearest university.

Figure [B1](#) presents our estimates examining distance linearly and compares Figure 4 (Panel A) in the main text. We find no significant relationship between distance and manufacturing before 1800. After 1800, cities far from universities are at a large and significant disadvantage in manufacturing. Consistent with our baseline estimates in the main text, the shift is largest 1800-1859 but is also observed 1860-1899.

To clarify magnitudes, we present estimates measuring distance in 100 kilometer units. Thus in Figure B1, the left hand panel examines the count of manufacturing and shows that a further 100 kilometers distance was associated with a -0.22 shift (decline) in manufacturing 1800-1859. Equivalently, our estimates indicate that a 60 kilometer *reduction* in distance to a university is associated with a 0.13 *increase* in the count of manufacturing events. The magnitudes of these estimates compare to our baseline estimates in which cities “close” to a university, defined as those below median distance and thus within 60 kilometers, enjoyed a 0.14 increase in the count of manufacturing events (see Figure 4 and Table 2 in the main text). These shifts also compare to the mean count outcome of 0.27.

Figure B1: Distance to Universities and Manufacturing



This graph presents regression estimates in which the outcome is manufacturing events in a city-time-period. The figure plots estimates on the interactions between distance to a university, measured in 100 kilometer units, and time period indicators. Each graph reports estimates from two regressions which correspond to the specifications in Figure 4. The first regression estimates the response of manufacturing to universities in two post periods: 1800-1859 and 1860-1899, relative to the reference period 1760-1799. These estimates and 95% confidence intervals are represented by shaded boxes. The second regression estimates a flexible model in which “University” is interacted with time period indicators, with 1780-1799 the reference period. All models include city and time fixed effects. Standard errors and 95% confidence intervals estimated following Conley (1999) allow for arbitrary spatial correlation within 25 km.

B.2 New Universities and Manufacturing

The fact that new universities were established in the period we study naturally raises a question: did the new universities have a more or less pronounced relationship with

manufacturing than the historic universities?

To address this question, we examine the heterogeneity in the university effect across old and new universities. We specifically test whether cities close to new universities experienced any differential shifts in manufacturing over and above those common across all cities near to universities. We extend our baseline analysis, reported in Figure 4 (Panel A), by including in the estimating model interactions between indicators for cities close to new universities and indicators for time periods. We use these interactions to estimate the incremental shift in manufacturing explained by exposure to new universities. The variation we study here arises from 284 cities which became “close” to universities in the early 1800s due to shifts in university locations, including the foundation of the universities at Berlin and Munich. As before, we define cities below median distance to a university as “close.”

Table B1 shows that cities near new universities enjoyed no clear advantages. Between 1800 and 1859, our estimates indicate virtually zero difference in manufacturing in cities near new universities compared to cities near pre-existing universities. Over the 1860-1899 period, there is some modest evidence that manufacturing increased more in cities near the new universities. This effect is statistically insignificant when we examine the count of manufacturing events (Column 1) and weakly significant when we examine the binary outcome recording whether any manufacturing is observed (Column 2).

While these findings should be interpreted carefully, the evidence indicates that the development of manufacturing around new universities proceeded in manner similar to that observed around pre-existing universities. This, in turn, suggests a broadly shared dynamic in which the university system as a whole had important implications for industrial development after 1800 and casts some doubt on the idea that the new universities at Berlin and Munich were unique and potentially endogenous drivers of development.

B.3 Pre-existing Universities and Manufacturing

The baseline analysis in the main text examines shifts in manufacturing for cities closer to and farther from universities. We focus our main analysis on differences in cities’ exposure to universities that were open in the 1800s and show that the effects we estimate are not driven by changes in university locations. In particular, we show that when we restrict the

Table B1: New Universities and Manufacturing

	(1)	(2)
	Manufacturing Count	Manufacturing Binary
University \times 1800-1859	0.14*** (0.04)	0.07*** (0.02)
University \times 1860-1899	0.06* (0.03)	0.03 (0.02)
New University \times 1800-1859	0.01 (0.06)	-0.00 (0.02)
New University \times 1860-1899	0.04 (0.05)	0.04* (0.02)
City and Time Period FE	Yes	Yes
Observations	15778	15778

This table reports regression estimates examining the count and presence of manufacturing events between 1760 and 1899. “University \times 1800-1859” interacts an indicator for cities below median distance to a university in the 1800s with an indicator for the 1800-1859 period. “University \times 1860-1899” interacts an indicator for cities below median distance to a university in the 1800s with an indicator for the 1860-1899 period. “New University \times 1800-1859” and “New University \times 1860-1899” interact indicators for cities that became close to a university due to the founding of new university. The estimated models include and city and time fixed effects and correspond to Figure 4, Panel A (equivalently, Table 2, columns 1 and 6). Standard errors are estimated allowing for arbitrary spatial correlation within 25 kilometers following the methodology of [Conley \(1999\)](#).

analysis to cities for which university exposure did not change over the period we study that we obtain similar estimates of the “university effect.”

Differences in historic exposure to universities as they existed before the French Revolution provide another lens through which we can examine shifts in manufacturing. Given that universities were not associated with differences in the level or trend of manufacturing before the political shocks of the late 1700s, and that these shocks were transmitted through universities, differences in exposure to pre-1789 universities offer comparisons somewhat akin to intention-to-treat analysis.

Figure B2 presents estimates that extend the analysis to study how exposure to pre-1789 universities explains manufacturing. We find that cities closer to pre-1789 universities experienced a positive shift in manufacturing after 1800 (Panel A), but that the estimated shift is quantitatively smaller than the shift we estimate when we restrict our analysis to cities for which university exposure did not change over this period (shown in Panel B). For example, for the count outcome we estimate a positive shift of 0.13 for cities close to universities in the 1700s (Panel A, left graph) and a positive shift of 0.18 for cities whose

Figure B2: Manufacturing and University Exposure Before and After Political Shocks



This figure presents regression estimates that extend our baseline analysis. Panels A studies how exposure to historic universities, active in the 1780s, explains shifts in manufacturing activity. Panel B replicates the corresponding panels in Figure 4. Panels A examines all cities ($n=2,254$). Panel B restricts analysis to cities whose university exposure did not change between the late 1700s and the 1800s ($n=1,686$). The models include city and time fixed effects as in the main text. Standard errors and 95% confidence intervals estimated following Conley (1999) allow for arbitrary spatial correlation within 25 km.

university exposure did not change (Panel B, left graph). The differences we observe reflect the fact that some pre-1789 universities closed and some new universities opened, making pre-1789 locations a noisy measure of actual university exposure after 1800.

B.4 University Closures and Prior Enrollment Trends

The fact that some universities closed during the period of political change running from the French Revolution through the Napoleonic era raises a natural question: were the universities

that closed better or worse, or more or less dynamic, than those that survived?

Enrollment patterns provide important indications of university quality, as they reflect the historic competitiveness of the German university system and the geographic mobility of students and faculty (Eulenburg 1904; Rüegg 2004a; Turner 1975). We therefore assemble university-year level data on enrollments from Eulenburg (1904) and test whether enrollments evolved similarly at universities that were and were not closed during the era of the French Revolution and Napoleonic invasion. We estimate:

$$enroll_{it} = \alpha_i + \delta_{decade} + \sum_{s=1700}^{1780} \beta_s(decade_s \times survive_i) + \epsilon_{it} \quad (2)$$

Here *enroll* is the number of students enrolled at university *i* in year *t*, the α are university fixed effects, the δ are decade fixed effects. The β_s estimate variation in enrollment specific to surviving universities in each decade. We measure the surviving universities with a time invariant indicator (*survive*) for universities that survived to 1820.

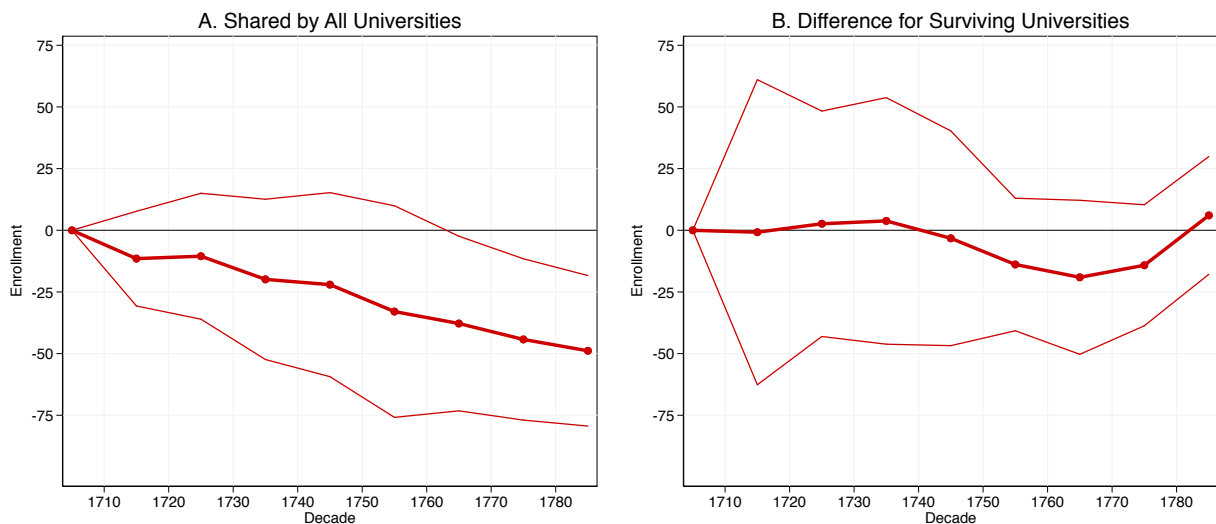
Figure B3 plots our estimates and shows that there was a secular decline in enrollments for all universities (Panel A) and no significant shifts in enrollments for universities that survived the politically-driven closures of the late 1700s and early 1800s (Panel B). This evidence is consistent with the view that university closures were driven by political events and did not, for example, lead to the selective closure of weaker institutions. This evidence is also consistent with view that German university education was in a long-running decline before the political shocks of the late 1700s (Turner 1975).

B.5 Urban Construction Before 1800

Urban construction is an important indicator of preindustrial development (Cantoni, Dittmar, and Yuchtman 2018) and provides evidence that enables us to further test whether cities near university locations were developing differently in periods before 1800.

We test whether urban construction differed across cities nearer to and farther from universities using data on major construction events from Cantoni, Dittmar, and Yuchtman (2018) and Keyser (1939-1974).

Figure B3: University Enrollment Dynamics Before the French Revolution



This graph plots regression estimates examining enrollments at German universities. Graphs report estimates from equation (2), in which the outcome is the number of students enrolled in a university-year. Panel A plots decade fixed effects. Panel B plots parameter estimates on the interaction between (i) decade fixed effects and (ii) an indicator for universities that survived the French Revolution and Napoleonic invasion and were not closed. Graphs present point estimates and 95 percent confidence intervals. Data on enrollments at the university-year level are from [Eulenburg \(1904\)](#). The surviving universities that remained open through 1820 are: Breslau, Erlangen, Freiburg, Giessen, Göttingen, Greifswald, Halle, Heidelberg, Ingolstadt, Jena, Kiel, Königsberg, Leipzig, Marburg, Paderborn, Rostock, Tübingen, and Würzburg. The universities closed by 1820 are: Altdorf, Bamberg, Duisburg, Erfurt, Frankfurt, Fulda, Helmstedt, Herborn, Köln, Mainz, Strassburg, and Wittenberg.

Our analysis (A) focuses on the development of manufacturing and on evidence from the mid-1700s through the 1800s and (B) reveals that there were not significant differences between cities close to and . A natural question is whether development trends in other, core outcomes were similar before the changes we study and outside manufacturing. City construction is a fundamental indicator of pre-industrial development that is consistently observed across all cities in our dataset. We therefore test whether cities near universities experienced any differential construction trends.

First, we test for cross-sectional differences in construction before 1800. We estimate regressions that test whether cities close to universities experience more construction in the late 1700s, across the 1700s, and over periods stretching back to 1500. We estimate

Table B2: Test for Pre-Trends in Urban Construction

	(1)	(2)	(3)	(4)
	Outcome: Urban Construction Events			
	1400-1799	1500-1799	1600-1799	1700-1799
University \times Trend	-0.0020 (0.0086)	0.0037 (0.0128)	-0.0110 (0.0197)	0.0176 (0.0584)
City & Time FE	Yes	Yes	Yes	Yes
Observations	44820	33615	22410	11205

This table reports panel regression estimates examining the number of major construction events in a city-period, measured as a 20-year period. “University” is an indicator for cities below median distance to a university in the 1800s and “Trend” is a linear time trend measured in 100-year units. Data on construction are from [Cantoni, Dittmar, and Yuchtman \(2018\)](#) and [Keyser \(1939-1974\)](#). Standard errors are estimated allowing for arbitrary spatial correlation within 25 kilometers following the methodology of [Conley \(1999\)](#).

regressions of the form:

$$construction_i = \alpha + \beta university_i + \epsilon_i$$

Table [B3](#) reports our findings and shows that we find no large and no statistically significant differences in construction for cities near to universities before 1800. This holds when we examine all cities in our data (Panel A) and when we examine cities whose university exposure did not change around 1800 due to the establishment or closure of nearby universities (Panel B).

We next test whether construction shifted over time towards cities near university locations. We investigate whether there were differences in urban construction in cities that were university locations in our main analysis. We estimate panel regressions of the form:

$$construction_{it} = \alpha_i + \delta_t + \sum_s \beta_s (university_i \times time_s) + \epsilon_i$$

Here $university_i$ is a time-invariant indicator for cities that were close to university locations in our main analysis, defined as below median distance in the 1800s. We obtain similar results examining a time-varying measure of actual university locations.

Figure [B4](#) reports our results and shows there were no significant shifts in construction towards university cities in the run-up to the political shocks and development of research

Table B3: Urban Construction Before 1800

	(1)	(2)	(3)	(4)
	Outcome: Urban Construction Events			
	1760-1799	1700-1799	1600-1799	1500-1799
<i>A. All Cities</i>				
University	0.02 (0.07)	0.08 (0.19)	0.06 (0.27)	0.18 (0.33)
Observations	2254	2254	2254	2254
Mean	0.64	2.04	3.54	4.73
<i>B. Cities with No Change in University Exposure</i>				
University	-0.02 (0.08)	0.02 (0.20)	-0.02 (0.30)	0.17 (0.37)
Observations	1686	1686	1686	1686
Mean	0.61	1.92	3.37	4.54

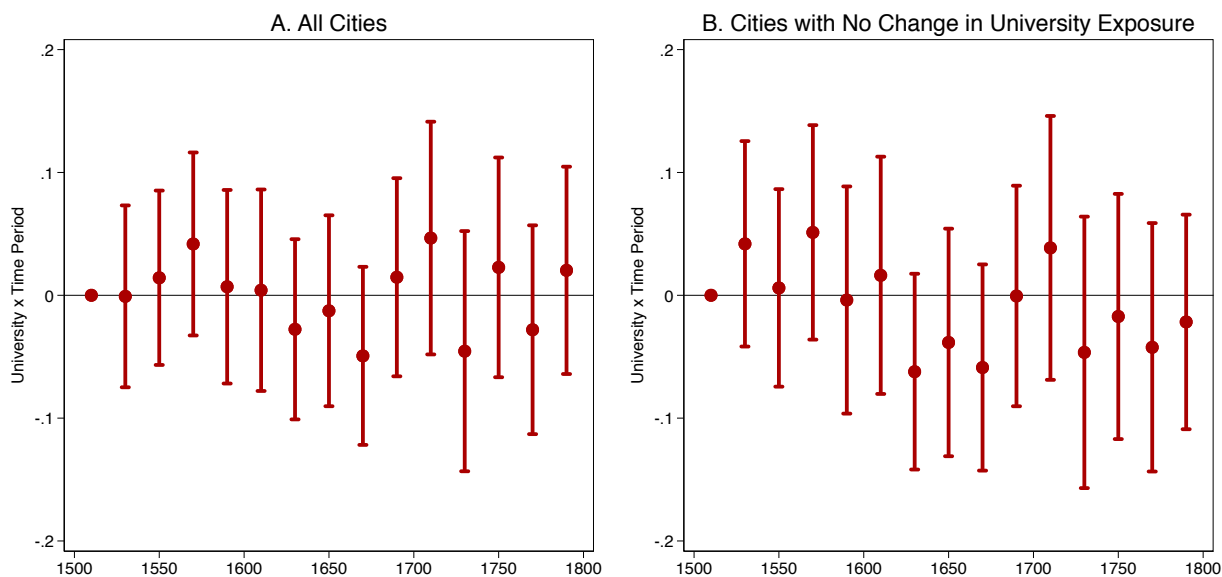
This table reports cross-sectional regression estimates examining the number of major construction events in a city. The outcome is the total number of major construction projects over the time period indicated in each column. “University” is an indicator for cities below median distance to a university in the 1800s. Data on construction are from [Cantoni, Dittmar, and Yuchtman \(2018\)](#) and [Keyser \(1939-1974\)](#). Panel A studies all cities in the data. Panel B studies cities whose university exposure did not shift between the late 1700s and the 1800s. Standard errors are estimated allowing for arbitrary spatial correlation within 25 kilometers following the methodology of [Conley \(1999\)](#).

universities circa 1800.⁴⁵

Our estimates indicate that urban construction developed similarly closer to and farther from universities before the industrial revolution. This result relates to [Cantoni and Yuchtman’s \(2014\)](#) finding that Germany’s first universities, which were founded due to the exogenous shock of the Papal Schism in the late 1300s, were associated with spatial differences in the spread of market rights in the late 1300s and early 1400s. In contrast, we find no evidence of systematic or lasting differences in city construction associated with universities within Germany. While we focus on the period from 1500 through 1800 in our quantitative analysis, the pattern we find holds in earlier periods as well. However, whereas [Cantoni and Yuchtman \(2014\)](#) focus on shifts in legal institutions associated with plausibly exogenous university foundations over a relatively tight time frame (between 1366 and 1406), we examine urban construction over longer time horizons and the implications of universities founded after and for other reasons than the shock of the Papal Schism.

⁴⁵We have also directly tested for and found no significant differences in construction trends for cities close to and far from university locations.

Figure B4: Urban Construction Before 1800



This graph plots regression estimates examining urban construction 1500-1799. The outcome is the number of construction events in a city-time-period. Time is defined in 20-year intervals. The graph plots estimates on the interaction between an indicator for cities close to university locations and indicators for time fixed effects. University proximity is measured with an indicator (“University”) for cities below median distance to a university in the 1800s. Graph A examines all cities in the data. Graph B examines cities whose exposure to universities did not change between the late 1700s and the mid-1800s. The estimated regressions include city and time period fixed effects. Standard errors estimated allowing for arbitrary spatial correlation within 25 kilometers following the methodology of [Conley \(1999\)](#) are used to compute 95 percent confidence intervals.

B.6 The Role of Universities and Economic Societies

To assess the role of universities, it is important to also consider other organizational changes related to the diffusion of knowledge. Notably, a number of “economic societies” were established in the late 1700s, animated by enlightenment ideas concerning progress and technology. [Cinnirella, Hornung, and Koschnick \(2022\)](#) indicate that economic societies contributed to the diffusion of useful knowledge, and notably find that patenting was higher in cities exposed to these societies in the period after 1870. The natural question for our study is whether exposure to these economic societies, which were established in 16 cities in our data in the very late 1700s, may be correlated with university exposure and account for some component of the university effect.

To examine the role of economic societies, we extend our analysis. We test (1) whether the university effect estimates change when we account for cities’ exposure to economic societies

Table B4: Universities, Economic Societies, and Manufacturing

	(1)	(2)	(3)	(4)	(5)	(6)
	Manufacturing Count			Manufacturing Binary		
University \times 1800-1859	0.14*** (0.04)		0.14*** (0.04)	0.07*** (0.02)		0.07*** (0.02)
University \times 1860-1899	0.07** (0.03)		0.07** (0.03)	0.04** (0.02)		0.04** (0.02)
Economic Society \times 1800-1859		0.00 (0.04)	-0.02 (0.04)		0.02 (0.02)	0.00 (0.02)
Economic Society \times 1860-1899		0.01 (0.04)	-0.00 (0.04)		-0.01 (0.02)	-0.02 (0.02)
City and Time Period Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	15778	15778	15778	15778	15778	15778

This table reports regression estimates examining the count and binary presence of manufacturing events between 1760 and 1899. “University \times 1800-1859” interacts an indicator for cities below median distance to a university in the 1800s with an indicator for the 1800-1859 period. “University \times 1860-1899” interacts an indicator for cities below median distance to a university in the 1800s with an indicator for the 1860-1899 period. “Economic Society \times 1800-1859” and “Economic Society \times 1860-1899” interact indicators for cities near economic societies, defined as within 50 km. Data on location of economic societies are from [Cinnirella, Hornung, and Koschnick \(2022\)](#). The estimated models include and city and time fixed effects and correspond to Figure 4, Panel A (equivalently, Table 2, columns 1 and 6). Standard errors are estimated allowing for arbitrary spatial correlation within 25 kilometers following the methodology of [Conley \(1999\)](#).

and (2) whether manufacturing increased more after 1800 in cities exposed to economic societies. We measure exposure to economic societies with an indicator variable for cities close to cities housing such societies. We define cities within 50 kilometers of a society’s home base as exposed in our baseline analysis. However, we obtain similar results when we examine other distance thresholds and when we measure exposure using the membership size of different societies rather than a binary measure of exposure.

Table B4 reports our results. Columns 1-3 examine the number of manufacturing events in a city-period. Column 1 reports our baseline results (as in Table 2). Column 2 reports results examining proximity to economic societies. Column 3 presents estimates examining exposure to universities and economic societies. Columns 4-6 present parallel results examining the binary outcome recording whether any manufacturing is observed in a city-period.

We find that the university effects hold controlling for exposure to economic societies and that exposure to economic societies does not explain variation in industrial activity.

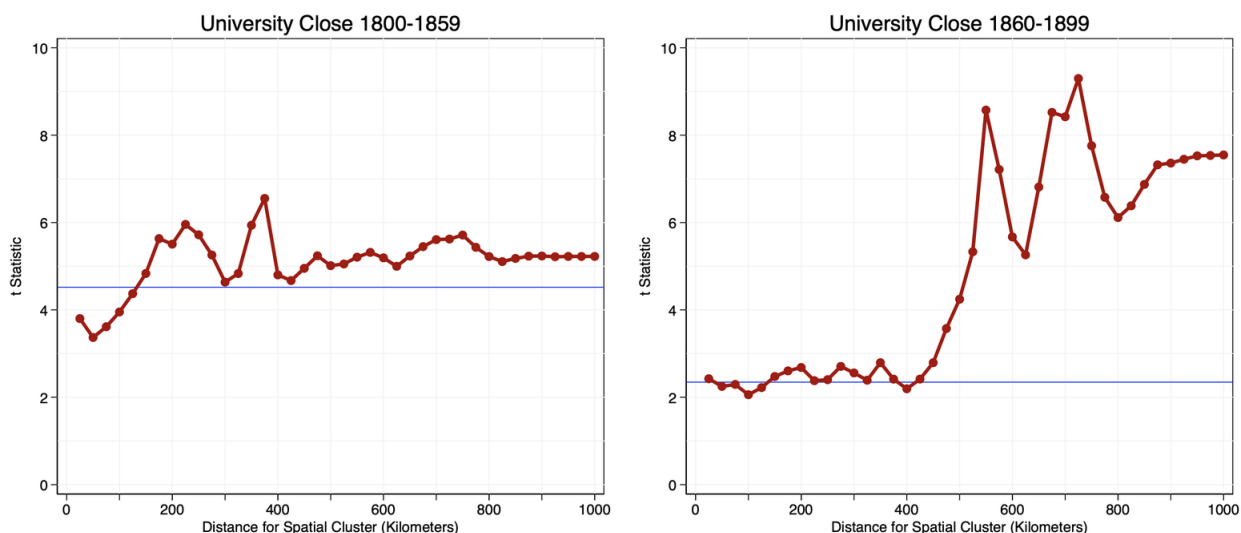
C Inference and Spatial Autocorrelation

C.1 Sensitivity of Standard Error Estimates

Our baseline analysis presents standard errors estimated following the methodology of [Conley \(1999\)](#) that allow for arbitrary spatial correlation within 25 kilometers. It is natural to wonder whether the choice of spatial cut-off is consequential for inference in our setting, and how these estimates compare to standard errors clustered at the unit (city) level.

To address this question, we re-estimate our baseline model varying the cut-offs for spatial correlation in the error structure. We re-estimate the model in [Table 2](#) (column 1) varying the cut-off from 25 to 1,000 kilometers. [Figure C1](#) plots the estimated t -statistics against the corresponding distance cut-off and shows we reject the null hypothesis of no shift in manufacturing for locations near universities across all distances. The estimated t -statistics are smallest (standard errors are largest) when we consider autocorrelation under 100 kilometers. In this region, [Conley \(1999\)](#) t -statistics are smaller than those obtained clustering at the unit level (shown by horizontal line in graph). But for all distances we estimate t -statistics over 3.0 on the interaction “University \times 1800-1859” (left-hand graph).

Figure C1: Inference Varying the Distance of Spatial Correlation



This graph presents the t -statistics on our baseline estimates [Table 2](#), column 1 as we vary the threshold for spatial autocorrelation. The t -statistics are estimated allowing for arbitrary spatial correlation following [Conley \(1999\)](#). The horizontal (blue) lines indicate the corresponding t -statistics estimated by clustering standard errors at the city-level.

C.2 Placebo University Locations

To further assess inference in settings characterized by spatial correlation, we can compare our baseline results to the distribution of estimates we obtain when we construct artificial spatially correlated data. We study the observed manufacturing outcome as it relates to placebo spatial data. We construct the placebo data by [1] assigning “artificial universities” to locations and [2] determining which cities were close to these placebo universities, defined by below median distance as in our baseline analysis. To do this, we randomly assign 19 artificial universities to locations in our data. We implement this in our baseline by assigning artificial universities to different 0.25×0.25 degree grid cells (approximately 27 kilometer by 27 kilometer cells).⁴⁶

We illustrate our findings by re-estimating the baseline regression specification in Table 2 (column 1) using placebo artificial universities to define university exposure. Figure C2 presents the distribution of parameter estimates we obtain for “University \times 1800-1859” over 1,000 draws of random spatial data, and compares this to our estimate when we examine the true historical data. Figure C2 shows that the $\hat{\beta}$ and t -statistics we estimate in the historical data are found far less than 5% of the time in the artificial placebo data.

C.3 Serial Correlation

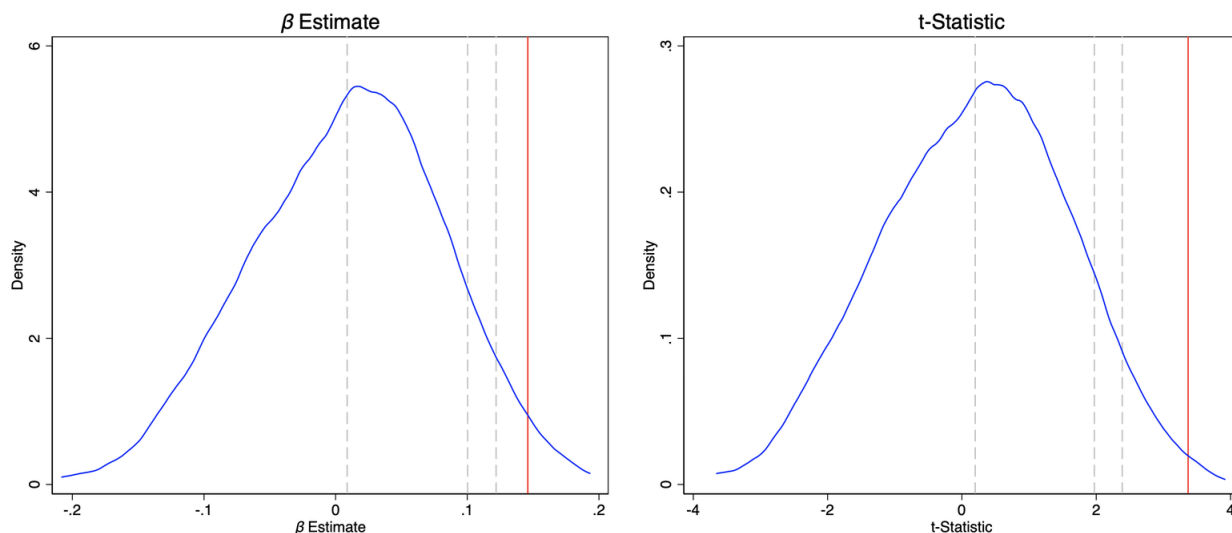
Inference in differences-in-differences designs can also be threatened by the presence of serial correlation in the data. Bertrand, Duflo, and Mullainathan (2004) show that one way to address potential problems due to serial correlation is to collapse panel data into two periods, a pre-period before and a post-period after the introduction of treatment.

We follow this approach using our data from 1760 through 1839. We thus examine the pre-period 1760-1799 and the post-period 1800-1839. We then test whether manufacturing shifted differentially in the post period for cities near to universities.

Our results support our baseline analyses. Table C1 shows we find highly significant effects of universities on manufacturing after 1800, consistent with our baseline findings.

⁴⁶Note that in our data many such grid cells contain multiple cities. Randomization at the level of the city generates “artificial university” locations that are relatively more concentrated in the most densely urbanized areas of historic Germany than actual universities were. However, even in this case our estimates are not consistent with a spatial noise falsification.

Figure C2: Distribution of Placebo Regression Estimates



This graph presents the distribution of estimates from placebo (spatial noise) regressions examining city-level manufacturing. The figure presents the distribution of estimates of the parameter on “Period 1800-1859 \times University Close” (Table 2, column 1). The estimates are obtained from 1,000 draws of random spatial data assigning “placebo universities” to 0.5×0.5 degree grid cells and then calculating which cities are above and below median distance to the placebo universities. The vertical dashed lines indicate the mean, 90th percentile, and 95th percentile of the distribution of placebo estimates. The t -statistics are estimated allowing for arbitrary spatial correlation within a range of 25 kilometers following Conley (1999). The solid vertical (red) lines indicate our estimates with the historical data (Table 2, column 1).

Table C1: Universities and Manufacturing in Pre-Post Comparison

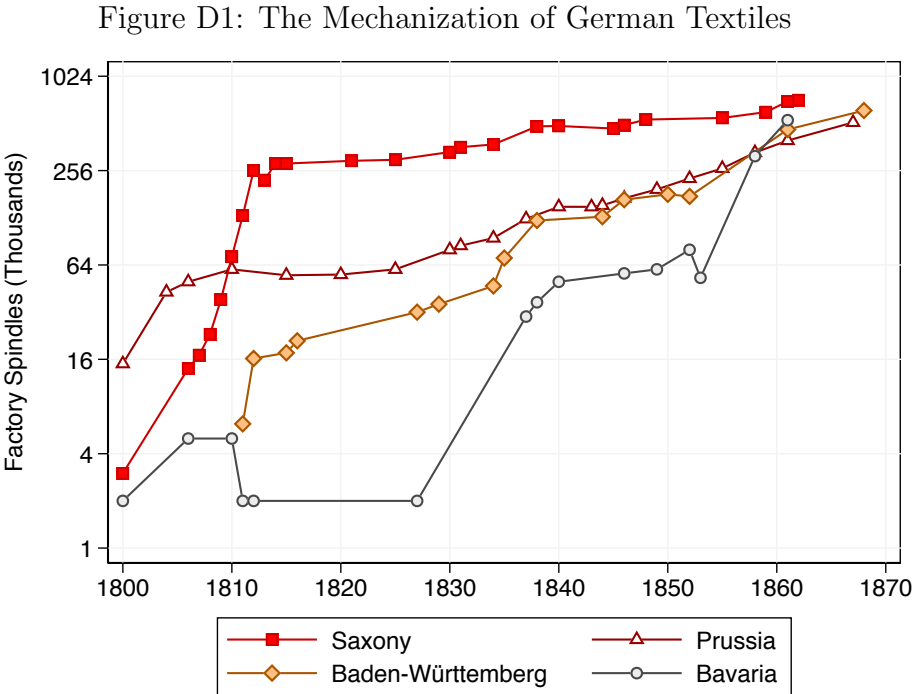
	(1)	(2)	(3)	(4)
	Manufacturing Count		Manufacturing Binary	
University \times Post 1800	0.14*** (0.03)	0.08*** (0.03)	0.06*** (0.01)	0.04*** (0.01)
Time fixed effects	Yes	No	Yes	No
Territory \times time fixed effects	No	Yes	No	Yes
Observations	4508	4508	4508	4508

This table reports regression estimates examining the count and presence of manufacturing events over the period 1760-1839. The outcome is manufacturing at the city-time-period level. The “Pre” period is 1760-1799. The “Post” period is 1800-1839. “University \times Post 1800” interacts an indicator for cities below median distance to a university with an indicator for the post-1800 period. All estimates include city fixed effects. The “Territory \times time fixed effects” interact indicators for territories with time period fixed effects. Standard errors are estimated allowing for arbitrary spatial correlation within 25 kilometers following the methodology of Conley (1999).

D Case Study Evidence on Industrialization in Saxony

D.1 Historical Background and Comparison to Other Regions

Prior research indicates that mechanized technologies diffused in the textile industry across Germany starting around 1800 and that Saxony was a leading region in this process (Tilly and Kopsidis 2020; Forberger 1982; Pollard 1981). Disaggregated evidence on mechanization at the establishment and city levels is limited outside Saxony. However, Kirchhain (1973) provides regional evidence on the number of spindles in textile factories, a key measure of mechanization. Figure D1 summarizes the data and shows that mechanization increased in the first decades of the 1800s and the increases were largest in Saxony.



This graph plots data on the number of spindles in textile plants across regions from Kirchhain (1973).

This evidence naturally invites a question about our analysis of manufacturing: was the university effect different in Saxony than in other parts of Germany? To consider this question, we test whether there was any difference in the post-1800 shift in manufacturing for cities near to universities if they were in Saxony as opposed to other regions. We extend the analysis in Table 3 (main text) to test whether in the post-1800 period university exposure is incrementally more or less predictive of manufacturing in Saxony. Table D1 reports our

results and shows that we observe no difference between the university effect in Germany and the university effect in Saxony in the data on manufacturing.

Table D1: Universities and Manufacturing in All Germany and in Saxony

	(1)	(2)
	Manufacturing Count	Manufacturing Binary
University \times Post 1800	0.13*** (0.04)	0.07*** (0.02)
University \times Post 1800 \times Saxony	-0.02 (0.12)	-0.00 (0.06)
Time-varying controls	Yes	Yes
Observations	9016	9016

This table reports regression estimates examining the count and presence of manufacturing events over the period 1760-1839. “University \times Post 1800” interacts an indicator for cities below median distance to a university with an indicator for the post-1800 period. “University \times Post 1800 \times Saxony” introduces as a further interaction an indicator variable for cities in Saxony. The estimates include time-varying controls, and city and time fixed effects. Table D1 Column 1 corresponds to Table 3 Column 2 in the main text. Table D1 Column 2 estimates the same model but examines the binary outcome measure. Standard errors are estimated allowing for arbitrary spatial correlation within 25 kilometers following the methodology of Conley (1999).

D.2 Quantitative Analysis of Mechanization in Saxony

In this section we present several additional pieces of evidence on mechanization in Saxony. We consider the sensitivity of our baseline estimates and potential spatial correlation.

Sensitivity of baseline results. The historical literature indicates that within Saxony manufacturing was concentrated in specific cities, with a particularly large concentration of firms in Chemnitz. It is natural, therefore, to wonder whether our results are driven by the number and technology choices of firms in Chemnitz or other leading cities. To examine this question, we re-examine the evidence first excluding Chemnitz from the analysis and then restricting the our analysis to cities with fewer than 10 establishments. As shown in Table D2, our findings when we restrict the sample in these ways are very similar to our baseline estimates (in Table 5).

Spatial correlation. Second, we present estimates of standard errors that account for arbitrary spatial correlation across different distance horizons. Table D3 presents OLS estimates corresponding to our baseline estimates in Table 5 in the main text. We estimate standard errors that allow for arbitrary spatial correlation over 10, 25, 50, and 100 kilometers.

Table D2: Mechanization and Universities Outside the Largest Cities

	(1)	(2)	(3)	(4)
	Data: Exclude Chemnitz		Data: Cities with < 10 Firms	
	Outcome: Number of Firms		Outcome: Number of Firms	
	Mechanized	Other	Mechanized	Other
University Close	1.43*** (0.55)	0.01 (0.59)	1.63*** (0.38)	-0.27 (0.67)
Observations	163	163	158	158

This table reports regression estimates examining the number of firms established in a city in a decade. Columns 1-2 exclude the city of Chemnitz from the analyses. Columns 3-4 restrict the analyses to cities with fewer than 10 factories and workshops established. The outcomes measure the number firms using mechanized or other (non-mechanized) technology established in a given decade. “University Close” is an indicator for cities below median distance to a university. These regressions are estimated with negative binomial regression. Heteroskedasticity robust standard errors in parentheses. Statistical significance at the 90, 95, and 99 percent confidence level denoted “*”, “***”, and “****”, respectively. Data are coded from [Forberger \(1982\)](#).

E Historical Changes in and Around Universities

Timing of Shifts in Research and Science. The narrative evidence strongly indicates that the development of scientific and technical research shifted and accelerated around 1800. Thus [Böhme and Vierhaus \(2002; p. 165 – our translation\)](#) observe that, “the natural sciences in the middle of the 18th century did not yet have the professionalism, reputation,

Table D3: Mechanization and Universities with Potential Spatial Correlation

	(1)	(2)
	Outcome: Number of Firms in City	
	Mechanized	Other
University Close	1.73	0.13
<i>Standard errors</i>		
Robust standard errors	0.83	0.17
Spatial standard errors 10 KM	0.83	0.17
Spatial standard errors 25 KM	0.77	0.12
Spatial standard errors 50 KM	0.66	0.11
Observations	164	164

This table reports regression estimates examining the number of firms established in a city 1800-1830. The outcomes measure the number firms using mechanized or other (non-mechanized) technology. “University Close” is an indicator for cities below median distance to a university. These regressions are estimated with OLS. Table reports heteroskedasticity robust standard errors, followed by standard errors allowing for arbitrary spatial correlation within 10, 25, and 50 kilometers following the methodology of [Conley \(1999\)](#). Data are coded from [Forberger \(1982\)](#).

and scientific level that only began to develop fifty years later.”

Significantly, pioneering developments in research infrastructure date from the late 1700s. For example, at Göttingen, scientific teaching and display collections of the Academic Museum, the Botanical Garden, the Observatory, the Chemical Laboratory, the Physical Cabinet made Göttingen a center of science at the end of the 1700s [Böhme and Vierhaus \(2002\)](#).

In what follows, we provide evidence on these changes across fields of knowledge and as they related to aspects of university structure and organization.

Chemistry. The first professorships of chemistry were established starting in the late 1700s and early 1800s. In 1789, a professorship in chemistry was established at Jena; additional professorships in chemistry were established at Erlangen in 1796 and 1807 and at Göttingen in 1810 (see [Schwedt 2002](#); p. 85). Significantly, these professorships were established in the philosophy faculty, which was in the process of being elevated as the center of scientific research (*Wissenschaft*) and *pre-date* the foundation of the university of Berlin. There was some variation across universities in these processes. For example, chemistry remained within the medical faculty at Leipzig until 1830 ([Krause 2003](#); p. 101-102), but the first chemistry lab at Leipzig university was set up in 1804/5. At Jena, a chemical laboratory – which was the predecessor to the chemistry institute – was established in 1811 on the top floor of the Duke’s palace. The chemistry institute was established in 1816, at Goethe’s initiative, and given new set-up in 1828 ([Schwedt 2002](#); p. 91).

Technology. A prominent example of how changes in universities promoted economically useful knowledge is the establishment of the Physical-Mechanical Institute (*Physikalisch-mechanische Anstalt*) at Jena in 1802. The institute was set up by mathematics professor Johann Heinrich Voigt and had as its explicit mission to promote scientific knowledge inside and outside the university, including in the private sector: “In 1802, Voigt noted deficiencies in training. Among his students there were two groups of listeners whose interests he could not do justice to in his lectures: mechanics who wanted to learn the scientific basics of their profession, and ‘normal’ students, who wanted to learn more about instruments.” ([Ziche 2001](#); p. 227 – our translation)

Significantly, Johann Heinrich Voigt observed that he was unable to satisfy young mechanics, who were not enrolled as fully matriculated university students but had been

attending university lectures to acquire scientific and mathematical knowledge for their professional work:

“Neither have I been able to satisfy any other class of participants in my lectures according to their wishes. These were not actual students, but young people who had learned practical mechanics and optics in so-called laboratories, but who had not had the opportunity to acquire the necessary scientific, mathematical-physical knowledge, knowledge which the heads of the most of the important laboratories in Germany have not had. These young people would therefore wish to go to the university for half a year or a year, to hear the lectures that are relevant to their art, but at the same time have the opportunity to continue their profession.” (cited in [Ziche 2001](#); p. 228 – our translation)

The Physikalisch-Mechanische Anstalt that Voigt established had three objectives (cited in [Ziche 2001](#); p. 229 – our translation):

“1) So that young mechanics, who attend to university, have the opportunity to use the appropriate laboratory under specific conditions, so that they are not idle. 2) so that other students who want to have classes in practical mechanics such as glass sanding, wood turning, etc have the opportunity [to take these classes] 3) so that when needed for math-physics lectures, new instruments can be bought and existing instruments can be modified and improved, supervised by the corresponding chair.

Notably, the institute was expressly designed to foster catch up with the technology progress in England. To achieve this goal, the institute hired three specialists: one scientific research manager, one marketing and sales manager, and one mechanic, who would supply teachers with instruments and mentor students.

Another example of university-based changes designed to promote economic catch-up and local spillovers is the establishment of the first chair in mineralogy and technology at Göttingen in 1811 ([Schlotter 1994](#); p. 186). This position were established with an eye on developing the local economy and investigating local resources.

Mathematics. The historical evidence suggests that mathematical research promoted technological innovation both directly and through spillovers. A notable example of a mathematics professor having a more or less direct positive impact on technical knowledge is Abraham Gotthelp Kästner at Göttingen. Kästner published influential text book that on mechanics and thermodynamics in 1799. However, we also observe important connections between basic scientific research, including by mathematicians, and concrete

technological break-throughs. For example, the research Carl Friedrich Gauß and Wilhelm Weber conducted on electricity and magnetism in the early 1800s led as a “*by-product*” to the discovery of the electrical telegraph (Schlotter 1994; p. 144).

Structure. One dimension of innovation in the structure of scientific research at universities involved the development of quasi-autonomous institutes and bodies outside the pre-existing faculties. For example, the chemical laboratory and botanical gardens formed at Jena in the 1780s were established outside the existing university faculties, by “extraordinary professors” who received their own funding and equipment (Ziche 2001; p. 140).⁴⁷ Ziche (2001) conclude that the such new institutions around the pre-existing faculties at the university of Jena played a critical role in the development of research in the early decades of the 1800s.

Quasi-independent institutes were established more broadly. For instance, the first institute established within the university of Marburg was the “State Economy Institute” (*Staatwirtschaftlichen Instituts*) founded in 1789, which offered lectures in economics, mining and metallurgy, forestry and agriculture, technology, chemistry, mathematics, physics, and statistics – among other subjects (Hermelink and Kaehler 1927; p. 451-2). More generally, the establishment of seminars transformed the nature of research conducted at universities, in particular by providing settings in teachers and students were able to collaborate in the 19th century (Krause 2003; p. 103-4).

Pro-science changes also reshaped the pre-existing faculties. Before the 1800s, the arts (philosophy) faculty ranked below the law, medicine, and theology faculties in importance and prestige. Over the first decades of the 1800s, scientific research was transferred to and consolidated in the arts faculties, which became centers of science. For instance, the university of Leipzig reorganized its faculty in 1809. In 1819, a new organization of training for Saxony pharmacists was introduced and “the first chemical laboratory of the university was established on the Pleißenburg in 1804/05” (Krause 2003; pp. 100-101). In 1821, Sachsen state parliament (Landtag) granted the university annual subsidy of 2,000 Reichsthaler on condition that it maintain transparent books. As these changes were consolidated, the value of a strong and well-staffed university gained traction (Hermelink and Kaehler 1927; p. 419).

⁴⁷Extraordinary professors were professors who were not appointed with chairs, in contrast with ordinary (full) professors.

F Schooling and Manufacturing

The Role of Schools. Our main analysis shows that the estimated relationship between universities and manufacturing holds accounting for presence of *higher schools*. It is natural to wonder whether the findings shift when we account for different levels and types of schooling and the *number* of schools and not simply the *presence* of schools. More generally, the relationships between the expansion of different types of schooling and industrial activity are themselves of economic interest and clarify our findings regarding universities.

Expanded Investigation. To measure the provision of education on different margins, we gather evidence on the establishment and operation of elementary schools, middle schools, trade schools, and technical colleges across all cities in our data. We classify schools as follows. We record and classify as “lower schools” all elementary schools (*Elementarschulen*), as well as a small number of “work schools” (*Arbeitsschulen*) and “charity schools” (*Armenschulen*). We separately record and classify all “middle schools” (*Mittelschulen*). We classify as “vocational schools” all vocational schools proper (*Berufsschulen*) as well as “advanced training” and “continuing education” schools (*Fortbildungsschulen*). We exclude from our analysis a small number of military schools (*Militärschulen*), music schools (*Musikschulen*), “seasonal schools” (*Saisonschulen*), and “special education” schools (*Hilfsschulen*). We also record where and when “Technical Higher Schools” (*Technische Hochschulen*), which were forerunners of later “technical universities,” were established. Our findings (below) are robust to alternate categorizations and the inclusion of all types of schools. The first *Technische Hochschulen* were established in the 1820s, as discussed in Section 2.2 (main text).

Quantitative Analysis. We extend our baseline quantitative analysis as follows.

We first examine how the presence of different types of schools was related to manufacturing in Table F1. Column 1 of Table F1 replicates the estimates in the main text for the 1760-1899 period (Table 3, Column 1). Our estimates of the relationship between universities and manufacturing hold almost unchanged when we separately control for the presence of lower, middle, and vocational schools and proximity to *Technische Hochschulen* (Table F1, Column 2). Our estimates of the university effect are stable even as we find a significant relationship between the presence of middle schools and vocational schools

and manufacturing outcomes when we study evidence including the late 1800s. Over this period, we find no positive relationship between manufacturing and proximity to *Technische Hochschulen*, which we measure with an indicator for cities within 50 kilometers of such a school. Our results are similar using other measures of distance to such technical schools.

We next focus on manufacturing between 1760 and 1839, before the build out of the railroad network. Column 3 replicates the estimates in the main text. Column 4 shows that these estimates again hold almost unchanged when we separately control for lower, middle, and vocational schools and *Technische Hochschulen*. Over the period through 1839 we find no large or statistically significant relationship between middle schools and vocational schools and manufacturing. This confirms that over the key period in which universities drove an early positive shift in industrial activity the presence of schools at lower levels had a relatively weak and more diffuse relationship to economic development. Over this period, we find a positive, weakly significant relationship between manufacturing *Technische Hochschulen*.

A natural question is whether manufacturing may have shifted with the number of schools in a city, which might reflect the intensity of educational provision or other time-varying factors. We therefore expand our analysis to account for the numbers of different types of schools. As shown in Table F2, our key findings are unchanged when we account for the number of different schools in a city (Columns 1 and 2). As in our baseline analysis examining the *presence* of schools, we find that only the *number* of higher schools had a significant relationship with manufacturing in the pre-1840 (column 4). Controlling for the number of schools at different levels, we find no significant relationship between manufacturing and proximity to *Technische Hochschulen*.

Several observations on the findings are worth noting. The pattern we document, in which university exposure is a robust predictor of manufacturing after 1800, holds controlling for different aggregations and disaggregations of the data on schools. In addition, the fact that proximity to *Technische Hochschulen* is not a strong explanatory factor warrants further study, but may be interpreted in light of the following. First, over the pre-1840 (pre-railroad) period, there is a positive if diffuse relationship between manufacturing and proximity to these technical institutions. Second, the very first of these institutions were only established in the 1820s, so exposure was limited in the pre-railroad era. Third, broadly speaking our results suggest that the pattern of local economic spillovers associated with knowledge

production was strongest before the railroad era. This may help explain why technical higher schools, which developed most strongly in the later 1800s, were not so clearly associated with *local* shifts in manufacturing.

Table F1: Universities, the Establishment of Schools, and Manufacturing

	(1)	(2)	(3)	(4)
	Outcome: Count of Manufacturing Events			
	1760-1899		1760-1839	
	Baseline	All Schools	Baseline	All Schools
University \times 1800-1859	0.14*** (0.04)	0.13*** (0.04)	0.13*** (0.03)	0.13*** (0.03)
University \times 1860-1899	0.06* (0.03)	0.06* (0.03)		
Railroad Connection	0.24*** (0.05)	0.23*** (0.05)		
Coal \times Post-1840	0.13** (0.06)	0.12** (0.06)		
Coal \times Post-1800	-0.03 (0.05)	-0.03 (0.05)	-0.02 (0.04)	-0.02 (0.04)
Free Enterprise Law	0.10** (0.04)	0.10** (0.04)	0.07 (0.04)	0.07 (0.04)
Early Manufactures \times Post-1800	0.15*** (0.05)	0.15*** (0.05)	0.20*** (0.08)	0.20*** (0.08)
Higher School: Indicator	0.18*** (0.04)	0.15*** (0.04)	0.20*** (0.07)	0.18** (0.07)
Lower School: Indicator		0.03 (0.03)		0.06 (0.04)
Middle School: Indicator		0.07** (0.03)		0.06 (0.06)
Vocational School: Indicator		0.08** (0.03)		0.03 (0.07)
Technische Hochschule		-0.03 (0.06)		0.06* (0.04)
City and Time Fixed Effects	Yes	Yes	Yes	Yes
Observations	15778	15778	9016	9016

This table reports regression estimates with variables defined as above. “Railroad Connection” and “Free Enterprise Law” are indicators constructed from [Kunz and Zipf \(2008\)](#) and coded following [Acemoglu et al. \(2011\)](#), respectively. “Early Manufactures \times Post-1800” interacts an indicator for post-1800 periods and an indicator for pre-1760 manufacturing activity. “Coal \times Post-1840” and “Coal \times Post-1800” interact an indicator for proximity to coal fields with time period indicators. The schooling indicators measure whether schools of a given type are present in a city, as described in the text. “Technische Hochschule” is an indicator for cities within 50 kilometers of such an institution in a given period. Standard errors allow for arbitrary spatial correlation within 25 kilometers following methodology of [Conley \(1999\)](#). Statistical significance at the 90, 95, and 99 percent confidence level denoted “*”, “**”, and “***”, respectively.

Table F2: Universities, School Density, and Manufacturing

	(1)	(2)	(3)	(4)
	Outcome: Count of Manufacturing Events			
	1760-1899		1760-1839	
	Baseline	All Schools	Baseline	All Schools
University \times 1800-1859	0.14*** (0.04)	0.14*** (0.04)	0.13*** (0.03)	0.13*** (0.03)
University \times 1860-1899	0.06* (0.03)	0.06* (0.03)		
Railroad Connection	0.22*** (0.05)	0.21*** (0.05)		
Coal \times Post-1840	0.14** (0.06)	0.13** (0.06)		
Coal \times Post-1800	-0.02 (0.05)	-0.02 (0.05)	-0.02 (0.04)	-0.02 (0.04)
Free Enterprise Law	0.10** (0.04)	0.10** (0.04)	0.07* (0.04)	0.07 (0.04)
Early Manufactures \times Post-1800	0.14*** (0.05)	0.13** (0.05)	0.20*** (0.08)	0.20*** (0.08)
Higher School: Count	0.09*** (0.02)	0.05*** (0.02)	0.08** (0.04)	0.06* (0.04)
Lower School: Count		0.03** (0.02)		0.01 (0.02)
Middle School: Count		0.00 (0.02)		0.07 (0.06)
Vocational School: Count		0.04** (0.02)		0.01 (0.03)
Technische Hochschule		-0.04 (0.06)		0.04 (0.04)
City and Time Fixed Effects	Yes	Yes	Yes	Yes
Observations	15778	15778	9016	9016

This table reports regression estimates with variables defined as above. “Railroad Connection” and “Free Enterprise Law” are indicators constructed from [Kunz and Zipf \(2008\)](#) and coded following [Acemoglu et al. \(2011\)](#), respectively. “Early Manufactures \times Post-1800” interacts an indicator for post-1800 periods and an indicator for pre-1760 manufacturing activity. “Coal \times Post-1840” and “Coal \times Post-1800” interact an indicator for proximity to coal fields with time period indicators. The schooling count variables measure the number of schools of a given type present in a city, as described in the text. “Technische Hochschule” is an indicator for cities within 50 kilometers of such an institution in a given period. Standard errors allow for arbitrary spatial correlation within 25 kilometers following methodology of [Conley \(1999\)](#). Statistical significance at the 90, 95, and 99 percent confidence level denoted “*”, “**”, and “***”, respectively.