Web Appendix to Becker/Hornung/Woessmann, "Education and Catch-up in the Industrial Revolution"

Appendix A: Data Sources

We have compiled a county-level database covering all 334 Prussian counties (as of 1849) over virtually the whole 19th century, from 1816 over 1849 to 1882. The data were collected in several censuses by the Prussian Statistical Office, which we combine from several archives. We accounted for changes in the administrative boundaries of counties by adjusting all sources to the 1849 county borders. The county-level data for 19th-century Prussia is viewed by demographers as a unique source of highest-quality data for analyses at a micro-regional level (cf. Galloway, Hammel, and Lee 1994).

Population and Establishment Censuses 1816, 1819, and 1821

The Prussian Statistical Office, founded in 1805, started to publish detailed data at the county and municipality level in 1825. The data contain information from censuses in 1816, 1819, and 1821. The 1816 and 1821 censuses provide information on population, demography, religion, and livestock. Information on schooling is provided only in 1816. The 1819 census provides data on establishments and means of production. These are, to our knowledge, the earliest censuses that lend themselves to a microeconometric analysis of education and pre-industrial endowments.

The 1819 and 1821 censuses are reported for 330 counties, four of which were later subdivided into two counties by 1849. The structure of 330 counties had been constructed by an administrative reform in 1812. By the time of the 1816 census, however, the reform had not yet been established in the original Eastern part of Prussia, where the old structure with larger counties was still in effect. The 1816 census is thus reported for 289 units of observation. We converted the data to match the 330 counties of the later censuses, based on population data from the 1821 census. Throughout the paper, counties are clustered at a level of 280 independent units of observation, based on the old structure and accounting for the fact that some counties had to be combined first before they could be subdivided again into the new structure.

The county-level data report on public elementary schools (*Öffentliche Elementarschulen*), the only school type equally available in rural areas and towns at the time. In addition, the 1816 census reports school data for the 172 medium and large towns in Prussia, which provide additional information on types of schools available only in towns: private elementary schools (*Privat-Elementarschulen*), public middle schools for boys or girls (*Öffentliche Buerger- und Mittelschulen für Söhne oder Töchter*), and private middle schools for boys or girls (*Private Bürger- und Mittelschulen für Söhne oder Töchter*). Children at recommended school age (6 to 14 years) could either attend elementary schools or middle schools, which had a broader curriculum as well as more grades. To capture all children at recommended school age, county and town enrollment data are aggregated to compute enrollment.[1]

The 1816, 1819, and 1821 censuses are also used to compute a rich set of control variables measuring pre-industrial development and demography (see Appendix Table A1 in the main text).

The source of the 1816, 1819, and 1821 census data is Mützell (1825).

Population, Schooling, and Factory Censuses 1849

A collection of censuses from 1849 was published by the Prussian Statistical Office in seven volumes from 1851 to 1855. Our analyses employ the Population Census (Vol. 1), the Schooling Census (Vol. 2), and the Factory Census (Vol. 6a). All data are available for 334 counties.

The 1849 Schooling Census provides information on the number of schools, teachers, and students in public schools. The types of schools employed in our analysis are public elementary schools (*Öffentliche Elementarschulen*) and public middle schools for boys (*Öffentliche Mittelschulen für Söhne*) and for girls (*Öffentliche Schulen für Töchter, die nicht in den Begriff der Elementarschule fallen*). Children at recommended school age (6 to 14 years) could either attend elementary schools or middle schools, so that data are again aggregated.

The 1849 Factory Census provides information on the number of factories, machinery, and workers per factory for each county. It distinguishes 119 types of factories by the products fabricated. We calculated the share of factory workers in the total population. We also subdivide

[1] The 1816 school enrollment data were missing for the eleven counties of the district of Cologne. We imputed the data based on school enrollment data available in 1829 for all 59 counties of the Rhine Province (Preussisches Statistisches Landesamt 1829). Given a high correlation of 0.59 of the 1829 data with the 1816 data for the 48 counties with both datasets available, we regressed the 1816 data on the 1829 data and predicted the 1816 values for the eleven Cologne counties based on their 1829 values.

factories into three industrial sectors: workers in metal factories, workers in textile factories, and workers in all other factories except metals and textiles. The first sector includes processing of metals and production of metal products and machinery, as well as manufacture of stone and glass products. The second sector includes factories for spinning, weaving, dyeing, and apparel. The third sector includes factories that produce such products as rubber, paper, food, wood, and wax. In the textile sector, workers working on hand-driven looms and weavers working for their own accounts were not counted as industry workers.

The 1849 Factory Census also includes information on steam engines in different industries. We included steam engines employed in mining in our dataset.

The source of the 1849 census data is Statistisches Bureau zu Berlin (1851-1855).

Population Census 1871

The 1871 Population Census collected information on demographics, religion, and education. This is explicitly the very first census to ever survey literacy in Prussia. Literacy is measured as the ability to read and write among the population aged 10 years and older.

The source of the 1871 census data is Königliches Statistisches Bureau (1874).

Occupation Census 1882

The 1882 Occupation Census collected information on employment and self-employment across two-digit sectors for the Prussian counties. We calculate the share of manufacturing workers in the total population. The manufacturing sector is also subdivided into three sub-sectors: manufacturing of metals, manufacturing of textiles, and all manufacturing except metals and textiles. The sectors are computed to match the sectors of the 1849 Factory Census using the classification provided by the Prussian Statistical Office. The first sector includes mining, products from stone, glass and metals, machinery, and chemicals. The second sector includes textile, apparel, and cleaning industries. The third sector includes such manufacturing as paper, food, wood, and construction industries.

The source of the 1882 census data is Preussische Statistik (1884/85).

Appendix B: The Relevance of Education for Industrialization

What is it that makes education relevant for industrialization, even in the first phase of the Industrial Revolution? Which types of education and curricular content facilitate the adoption of the new technical and organizational modes? We can only speculate on this, but it seems useful to classify different dimensions in which education may be relevant for industrial development and relate them to discussions in the literature and to our results. For the latter, we focus on the role of school education and basic literacy of the population at large in facilitating the regional emergence and growth of factories that use the new industrial technologies.

A first dimension in which education could facilitate industrial development is its role for entrepreneurship (cf. Kocka 1977 for a discussion in the Prussian setting and Bates 1990 as an example of modern evidence). Education may impart higher-level scientific skills and the ability to innovate necessary to advance technical knowledge. While this may seem foremost the task of higher education (for which we do not find significant effects),[2] it has been argued that a system of basic education that covers the broad masses is a pre-requisite to screen the highest-capable entrepreneurs and researchers. Thus, Landes (1980, p. 118) argues that "elementary schooling as such has been important … as a device for the recruitment of talent. … the bigger the pool one draws from, the better the chances of finding gifted and original scientists and technicians." Although this genuinely innovative dimension of the role of education may have gained relevance in some sectors (such as certain electrical and chemical industries) during the second phase of Prussian industrialization, the foremost task relevant for early Prussian industrialization rather seems to have been imitation.

A second dimension at the other extreme is the direct productive use of skills, at work even in a purely stationary economy. If the tasks of a factory require a certain minimum level of skills, such as the ability to read basic instructions and perform basic calculations, then an entrepreneur cannot establish and run a factory in a region where the whole population lacks basic literacy. Formal education may also impart behavioral traits and non-cognitive skills that are relevant for factory production, such as conscientiousness, dependability, self-control, discipline, punctuality, responsibility, orderliness, and perseverance (e.g., Field 1989; Bowles, Gintis, and Osborne 2001). In addition, industrial production creates service jobs that require literacy and numeracy

[2] Higher education may also not have been particularly oriented towards technical sciences or economically usable skills in Germany at the time (Weber 2003).

skills, such as accountancy, commercial transactions, banking, insurance, and lawyers (e.g., Anderson and Bowman 1976; Allen 2009). As Laqueur (1974, p. 103) argues, the industrial "economy require[d] supervisory personnel … [and] created a whole mass of ancillary jobs in engineering, transport, trade, retailing, finance and the older artisanal trades."

Although both static skills and purely innovative abilities may have their relevance for industrialization in 19th-century Prussia, it seems that rather a third dimension is of prime importance in the context of industrial catch-up: the role of education in the adoption of new technologies. In motivating their catch-up model of technological diffusion, Nelson and Phelps (1966, p. 69) argue that "probably education is especially important to those functions requiring adaptation to change. Here it is necessary to learn to follow and to understand new technological developments." This dimension of education, the ability to adjust to changing conditions, seems of particular importance in the Prussian setting after 1815, where the Stein-Hardenberg reforms unleashed the potential to adapt to the changed environment of newly available technologies.

In a dynamic setting of changing technology, education plays a particular role by fostering the "ability to deal with disequilibria" (Schultz 1975), i.e., to perceive a given disequilibrium, to evaluate its attributes properly in determining whether it is worthwhile to act, and to undertake action to appropriately reallocate resources. Such abilities are particularly relevant when technical change is disruptive rather than incremental, as is the case for most industries emerging during the Industrial Revolution (with the possible exception of textiles, see Web Appendix D). Education may enhance "allocative ability in the sense of selecting the appropriate input bundles and of efficiently distributing inputs between competing uses" (Welch 1970, p. 55). According to Schultz (1975, p. 835), "The presumption is that education – even primary schooling – enhances the ability of students to perceive new classes of problems, to clarify such problems, and to learn ways of solving them. … [These] abilities … seem to have general properties that contribute measurably to their performance as economic agents in perceiving and solving the problems that arise as a consequence of economic changes." Because this type of economic returns to education accrues only in a technically dynamic context, not in a static economy with stationary technology (see Bartel and Lichtenberg 1987; Foster and Rosenzweig 1996 for examples of modern evidence), the relatively high Prussian education level may not have been of similar economic relevance before the institutional reforms of the first two decades of the 19th century.

The skills necessary in this setting are multifaceted and general, rather than applied to one particular craft, and may be best described as a general understanding of the functioning of the world. They start with the basic “three R’s” of reading, writing, and arithmetic, required for commercial communication, accessing practical handbooks, decoding instructions, debugging new processes, reading books about foreign places – all relevant actions in the given historical setting (Anderson and Bowman 1976).[3] They may also encompass socialization and the creation of an aspiring human personality with attitudes favorable to adopting new technology (Easterlin 1981). Finally, literacy may create awareness of nonconventional possibilities; as Anderson and Bowman (1976, p. 7) put it, “Almost every effect of literacy includes an element of change in men’s perceptions of the alternatives in action that are open to them.” Note that the ability to reallocate one’s resources in response to changing conditions and the ability to discover and master new tasks is not restricted to entrepreneurs, but is useful and required for basically any economic activity at all stages of management and production (cf. Schultz 1975).

The Prussian school system that emerged at the start of the 19th century may have been particularly capable of delivering the abilities that are productive in this setting. Its educational ideal of an encompassing education aimed at providing the broad masses with the competency to think rationally and to act independently as a human being (see Web Appendix D). Even though the Industrial Revolution may initially have created demand for uneducated labor – and often child labor – to perform routine tasks in some industries, our evidence suggests that the previous arguments of the role of education in creating the ability to adjust to changing conditions may have been of resounding relevance in both phases of the Industrial Revolution in Prussia.

[3] In a similar vein, Vandenbussche, Aghion, and Meghir (2006) stress the particular role of primary and secondary education (as opposed to tertiary education) in the imitation process.

Appendix C: Examples of the Technological Adoption Process in Prussia

While the general idea that education fostered the ability to adapt to changing conditions is a concept that largely eludes depiction in concrete examples, there are plenty of historic examples of how education was important for the adoption of British technologies in Prussia in a narrower sense. This appendix presents a few of them. They range from the education of the entrepreneurs over specific examples of the role education played in the factories to technical colleges and the use of technical journals.

Pierenkemper (1994) highlights the role of education of the adopting entrepreneurs. As documented in extensive research by himself and other references in his study, German entrepreneurs in the 19th century had a remarkable level of general school education – with the interesting reservation that this is more apparent in the manufacturing industries than in the textile industry (see also Laer 1977, p. 213). Pierenkemper and Tilly (2004, p. 129) conclude: "[L]earning from abroad was an important part of the 'catching-up' syndrome... German entrepreneurs enjoyed better formal education [...] than their foreign competitors."[4]

An interesting example of the importance given to a sound basic education of workers on the factory floor comes from Heinrich Gerber, one of the most famous engineers of the 19th century and director of the bridge-building company Gustavsburg (later part of the M.A.N. conglomerate). Gerber characterizes his workforce in 1866 as follows: "Gustavsburg gains because our workers *have to have* a certain degree of intelligence; for this reason, different from the spinning industry and the like, we do not draw a large number of rude people."[5] (cited in Foth 1943, p. 4; emphasis added). Note, again, the difference that is made between manufacturing and textile industries.

Literacy and numeracy were necessary to read manuals and weighing balances. An example of an occupation where literacy was essential is that of puddlers, who worked on furnaces turning pig iron into wrought iron. Not only did this job require physical strength, stamina, and sustained concentration, but puddlers also carried out the book-keeping of material inputs which required reading, writing, and arithmetic skills (Fremdling 1985, p. 209).

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[4] For similar assessments, see also Buchheim (1995) and the references on the role of education for entrepreneurship in Web Appendix B.

[5] "Gustavsburg gewinnt dadurch, dass unsere Arbeiter einen gewissen Grad an Intelligenz haben *müssen*; daher nicht wie bei Spinnereien und dergleichen eine große Zahl roher Menschen beigezogen werden."

Factories tended to have written factory rules which required reading capabilities of factory workers. An example showing that literacy of factory workers was taken for granted comes from the factory order of 6th June 1844 of Cromford factories in Ratingen (see Landschaftsverband Westfalen-Lippe 2010). Paragraph 14 states that the factory rules are affixed in all factory halls so that nobody can be excused for not being aware of them.[6]

Basic education was not only useful in itself. More generally, it was a prerequisite for further, more technical education (for examples, see Becker 1962, p. 228; Laer 1977, pp. 313-214). Christian Peter Wilhelm Beuth, head of the department of trade in the ministry of finance, who was dedicated to promoting industrial development, fostered the foundation of trade schools and technical colleges (Henderson 1955). Those quickly became a distinguishing feature, as described by Landes (2003, p. 187) in his discussion of the diversity of outputs produced in the German chemical industry in the 19th century: "The experts attributed this versatility to the skill and training of the young technicians – not the savants, *but the production men*" (emphasis added). Similarly, analyzing the technical development in Germany, Radkau (2008, p. 104) reaches the conclusion that the key role that needs to be assigned to education and scholarship in technical development can be seen even more clearly in Germany than in other European countries.

Both entrepreneurs and Prussian civil servants went on study trips abroad to explore the "possibilities" that new technologies be brought to Prussia. Beuth travelled to England on several occasions, in 1826 accompanied by architect and painter K.F. Schinkel. Schinkel would draw 119 sketches (Lärmer 1998), many of which were printed in a journal entitled "Examples for Factory Owners and Craftsmen" (*Vorbilder für Fabrikanten und Handwerker*), which was published between 1821 and 1837. Obviously, education was crucial to be able to access and make use of these publications (see also Kroker 1971, pp. 40-49).

On a general basis, the role of education for the catch-up process was widely acknowledged by politicians and industrialists alike. As early as 1821, the "Association for the Advancement of Industrial Diligence in Prussia" (*Verein zur Beförderung des Gewerbefleißes in Preussen*) was founded. Prominent founding members include the state minister Baron vom Stein (known for the Stein-Hardenberg reforms) and the educational reformer Wilhelm von Humboldt. The

[6] "Damit niemand sich mit Unkenntniß der Fabrikordnung entschuldigen kann, wird dieselbe auf allen Sälen zur allgemeinen Kenntniß angeheftet."

association was also joined by famous entrepreneurs such as August Borsig (locomotives) and Ferdinand Schichau (steam engines). The chairman of the association was Beuth, who in his opening speech underlined the role of education[7] for the development and perfection of industry and the importance of self-initiative[8] of manufacturers. Beuth's motto was: "educate men of deep knowledge and ability…"[9] (Matschoss 1921, p. 27).

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[7] "Die Überzeugung, meine Herren, dass Gewerbefleiß die Grundlage der Wohlfahrt eines Landes sey, dass es mithin ein Verdienst sey, das Fortschreiten und Vervollkommnen der Gewerbe zu fördern, so wie insbesondere die Überzeugung, dass die *Bildung* einem Stande hauptsächlich Ansehn und Wichtigkeit in der bürgerlichen Gesellschaft gebe und sichre" (reprinted in Rheilen 1992, p. 117; emphasis added).

[8] "so kann doch die aufmerksamste Regierung nicht alles sehn, es ziemt ihr auch nicht, alles für Andre zu thun, am Wenigsten aber kann sie die eigne Thätigkeit ersetzen" (reprinted in Rheilen 1992, p. 117).

[9] "erzieht Männer von tiefem Wissen und Können…"

Appendix D: Relation to Existing Evidence on British Industrial Revolution

Our results constitute a substantial change in the empirical assessment of the historical role of education in the transition to modern industrial growth. The literature so far has not found a similar education effect during the first phase of the Industrial Revolution in Britain (cf. Mitch 1999 for an encompassing review). We propose four likely reasons for the differing findings, all of which – while necessarily speculative – seem to us to carry some truth. The four arguments are data availability, specifics of the textile sector, differences between industrial leader and follower countries, and Humboldt's educational ideal.

The first and most likely cause for a lack of evidence in Britain is the lack of relevant data needed for a thorough test of the role of education in industrialization. Absence of proof is not proof of absence. The data situation in Britain is very different from Prussia. Industrialization in Britain started earlier, in the second half of the 18th century. But the first national schooling survey was in 1818 (Mitch 1999), and the first centrally administered census covering all household members was not conducted until 1841. As a consequence, British studies have to rely mostly on Parish registers (often drawing on poor proxies for education like signatures in marriage registers), which by necessity remain eclectic and limited in comparability compared to the representative data from full national censuses available in Prussia.

The main evidence underlying the argument of a limited role of education in British industrialization is that the level of education stagnated during the first phase of the Industrial Revolution in England and that its use actually declined in some leading sectors. Even though both findings are highly contested, they surely contain some truth (Mitch 1999). However, this is no evidence that education was not important for the *emergence* of industrial production and for development during the Industrial Revolution more generally (cf. Laqueur 1974 for a similar argument). It is clearly possible that education was relevant for the emergence and adoption of British industrialization in the late 18th century, while the demand for education then declined during the first phase of industrialization. Education may be required for the management, scientific, and engineering tasks to decipher, understand, and adopt a new technology and discover and master the tricks necessary in production. But once adopted, the technology gets standard, the production task ordinary, and education less important in production. To test the relevance of education for British industrialization, one would thus need cross-sectional data on education *before* the emergence of industrial technologies. The role of pre-existing education for industrialization in Britain has not been tested, and it seems that the required data do not exist.

The data argument also contains a deeper point. British evidence – including the growth-accounting analysis by Crafts (1995) – tends to focus on *changes* in education, as does Lundgreen's (1976) Prussian aggregate-level analysis for 1864-1911. However, if the theoretical framework of the technology diffusion models – which model the role of education not as a standard factor of production but as facilitating technological diffusion – is correct, it is not the *change* in education that is relevant for industrialization, but the *level* of education (cf. Krueger and Lindahl 2001).

Second, the focus of the existing Industrial-Revolution literature on cotton textiles may be misleading (cf. Komlos 2000). The bulk of British evidence on the role of education is for the textile sector, and it is there that education levels may actually have declined (Mitch 1999). According to our Prussian findings, the textile sector may be very different from most other industries in terms of the role of education. A possible reason for this is that innovations were much more incremental and less disruptive in textiles than in other industries. New technologies in textiles built closely on previously available technologies. By contrast, many other industries only emerged during the Industrial Revolution, or at least had their processes transformed much more radically. According to our theoretical framework, the role of education was much more limited where the need to adapt to radical change was less intensive. Because textile production existed before industrial times as a substantial sector, industrial development in textiles may have exhibited substantial path dependence (as evidenced by the effect of 1819 looms on 1849 textile factories in our regressions). This may have been aggravated by the existence of substantial sunk costs (as suggested by the fact evident in our archive data that hand-driven looms existed in the same factories next to mechanical ones for a long time; cf. also Henning 1995).

The incremental development also made applied types of sector-specific knowledge, more easily acquired through informal instruction on the job, more relevant in textiles than general types of knowledge acquired through formal education (cf. Crafts 1995, 1996 and Mitch 1999 on the substantial role of informal learning in Britain). Another possibility is that child labor was more prevalent in textiles than in other industries, reducing the estimated effect of education. Also, establishing industrial factories in textiles, where they displaced existing non-factory production, created more social unrest than in completely new industries (Weber 2003, p. 326), possibly inducing textile entrepreneurs to evade educated regions. Textile industrialization in Prussia was “very slow” and “extended over a whole century”, so that it was “not possible to speak of a take-off” in the German textile industry (Henning 1995, pp. 139, 144). In Prussia, an additional reason for this may have been cheap import competition (amplified by the fact that Prussia could not grow cotton and had no colonies at the time). As a consequence, in contrast to Britain, textiles were not a leading sector of industrialization in Prussia (Henning 1995).

While the first two points imply that education may have had the same effect in each sector in Britain as in Prussia, the remaining two points suggest a larger education role in Prussia.

The third point is the core argument of the leader-follower model outlined in Section I of the main text, where the role of education emerges from the need to adjust to exogenously determined changes. This makes education particularly relevant in an imitating country like Prussia at the beginning of its industrialization. By contrast, the factors determining the truly innovative development in the industrial leader country Britain may be different. As the innovation literature duly points out, much innovative activity has a lot of chance to it (cf. Crafts 1995 for an application to the Industrial Revolution), and the skills needed for innovation may (or may not) be quite different and less dependent on formal education than the skills needed for imitation. Of course, the application stage in some regions and factories in Britain may not have been too different from the catch-up phase in Prussia. But again, less formal forms of communication and instruction were available inside Britain that were not available for people outside Britain who had less interaction with the new technologies and even spoke a different language.

The fourth point refers to the type of education most relevant for the ability to adjust to change (cf. Web Appendix B). Here, the reforms of the Prussian education system famously initiated by Wilhelm von Humboldt as Prussian Minister of Education in 1808 receive particular relevance. As Jeismann (1987, p. 5) points out with regard to the 1806-1813 period of Napoleonic reign in Prussia, “The ‘period of the French’ was the incubation period of the German education system of the 19th century.” The education reforms had a key function in the more general Prussian reforms at the time, which presupposed a type of citizen able to act as self-responsible human being. Humboldt managed to initiate fundamental reforms of curricula, teaching methods, teacher education, and auditing in the school system. The reforms were rather pragmatic, and many sources report that as early as 1811, they were successfully implemented even in distant regions and had visible consequences in schools (cf. Schmitt 2001).

The reforms advanced Humboldt's humanistic educational ideal of an encompassing general education which aimed to implant the ability of rational thinking in the broad masses. The general knowledge of the Humboldt type may be particularly relevant to foster the ability to deal with economic disequilibria. According to the Handbook of German Education History (Jeismann 1987, p. 13), the expansion of the education system fostered industrial modernization with lasting effect, particularly "through an education, extending by and by into the broad masses, to ways of thinking that were oriented ultimately at scientific rationality, by familiarization with intellectual rigor, accuracy, and verifiability of the results of one's own endeavors." Although not focusing on specific technical abilities, the Prussian education system may thus have fostered the ability to learn how to learn, which provides the basis for independent study in a synergistic learning process (cf. Cunha and Heckman 2007 for a modern emphasis). Compared to other countries, Prussian schools may have taught a curriculum that was of particular use in adopting new technologies (cf. Easterlin 1981 for an example that a rationalistic education was not the uniform rule at the time). Somewhat ironically, although the Humboldt reforms were partly aimed against an excessively utilitarian type of education that conveyed just the skills necessary for a specific occupation, they may actually have imparted exactly the type of skills necessary for an economy in which adaptation to rapid change was asked for.

Appendix E: Further Examples of Historically Idiosyncratic Sources of Educational Variation between Neighboring Counties

This appendix discusses three further examples of historical idiosyncrasies that led to substantial educational variation between neighboring counties, in addition to the example of Swedish Western Pomerania (rectangle 1 in Figure 1) that is discussed in Section II.B in the main text.

The lightly shaded counties in the center of rectangle 2 in Figure 1 form Ermland, a mostly sovereign diocese before it came under Prussian rule in the first Partition of Poland in 1772. Ermland, which remained thoroughly Catholic, was surrounded by the Protestant Dukedom of Prussia. The Ermland counties had enrollment rates between 20% and 25% in 1816, whereas the surrounding Protestant counties – in line with Luther's urge for education – had enrollment rates of 75% in the west, 71% in the south, and 65% in the east. Note that while the religious source of this educational variation is the same as the one employed in the specification of Web Appendix F, this variation is not driven by distance to Wittenberg, but by historical peculiarities.

Another interesting neighboring difference is observed in the westernmost part (rectangle 3), where the starting point is virtually opposite. The areas of Geldern and Moers in the far west had been part of Prussia since 1702/03 (and had a Protestant share of about one quarter). However, apparently due to a lack of interest and enforceability in the western exclaves, the Prussians did not enforce their schooling ideals during the 18th century, so that the desolate state of the school system – evident in the low school enrollment figures in our data – became a topic of many school inspectorate reports in the early 1800s (Nagel 2004). By contrast, the neighboring counties to the east – which were part of the Prince-Bishoprics of Cologne and particularly Münster – although thoroughly Catholic and annexed by Prussia only in 1815, already had enrollment rates of 70% to 76% in 1816. Interestingly, the source of the relatively high level of schooling throughout the Prince-Bishopric of Münster can be traced back to the Catholic (!) order of the Jesuits, who used costless comprehensive schooling as a means to restore the population back to Catholic faith in the Counter-Reformation after 1588 (Schönemann 1993).

The counties of Liebenwerda and Hoyerswerda (west and east, respectively, in rectangle 4) had been part of the Lutheran heartland Electorate of Saxony for centuries before they joined Prussia at the Congress of Vienna in 1815. However, Hoyerswerda, as part of the Oberlausitz, was not directly subject to Saxon law because it had retained the right to maintain a local feudal tribute system and – in contrast to the Electorate of Saxony – placed little emphasis on education. Accordingly, in 1816 its enrollment rate of 44% was substantially below the 80% of neighboring Liebenwerda.[10]

[10] Another leading example of a Dukish quirk, although just outside Prussia in the German Empire, was Ernest I, the Pious, Duke of Saxe-Gotha, who – driven by his Lutheran faith – introduced effective compulsory schooling in his territory in 1642, still during the Thirty Years' War. It was proverbial that the Duke's peasants were better educated than the nobility elsewhere, and public saying has it that there was no one in his Dukedom unable to read and write when he died.

Appendix F: Distance to Wittenberg as an Alternative Instrument

We also experiment with a second approach to identification, proposed by Becker and Woessmann (2009) for the analysis of Protestant economic history. They observe that at the times of Martin Luther, Protestantism in Prussia had a tendency to spread in circles around Wittenberg, where Luther preached that every Christian should be able to read the Bible. They show that as a consequence, distance to Wittenberg gives rise to a decreasing prevalence of education in Prussia, and that Protestantism is unlikely to have had substantial economic effects besides its indirect effect through education. Based on this observation, we can use distance to Wittenberg *WITT* as an alternative instrument for education in the first stage of our model:

(A1)
$$EDU_{1849} = \alpha_4 + \beta_4 WITT + X'_{1849}\gamma_4 + \varepsilon_4$$

The advantage relative to our main approach is that this instrument directly models the source of the particular variation in the endogenous independent variable. But the specification requires the identifying assumption that Protestantism affected industrialization only by increasing education, which is in line with the findings in Becker and Woessmann (2009).

As the results in Table A4 reveal, distance to Wittenberg is indeed a strong instrument for our education measures both in 1849 and 1871. The specification confirms our main results: Education has a significant positive effect on total industrialization during both phases of the Industrial Revolution, which is strongly borne by industrialization outside metals and textiles.

In the metal industry, the effect is again marginally significant in the first phase and strongly significant in the second phase. By contrast, the effect is again insignificant in the textile industry (not shown) in the first phase (it gets significantly positive in the second phase in some but not all specifications). The coefficient for industries other than metals and textiles is substantially larger with the Wittenberg instrument than in the main specifications.[11]

[11] The difference in point estimates may result from different complier sub-populations being affected by the different instruments. Results are similar when we apply both instruments together (not shown).

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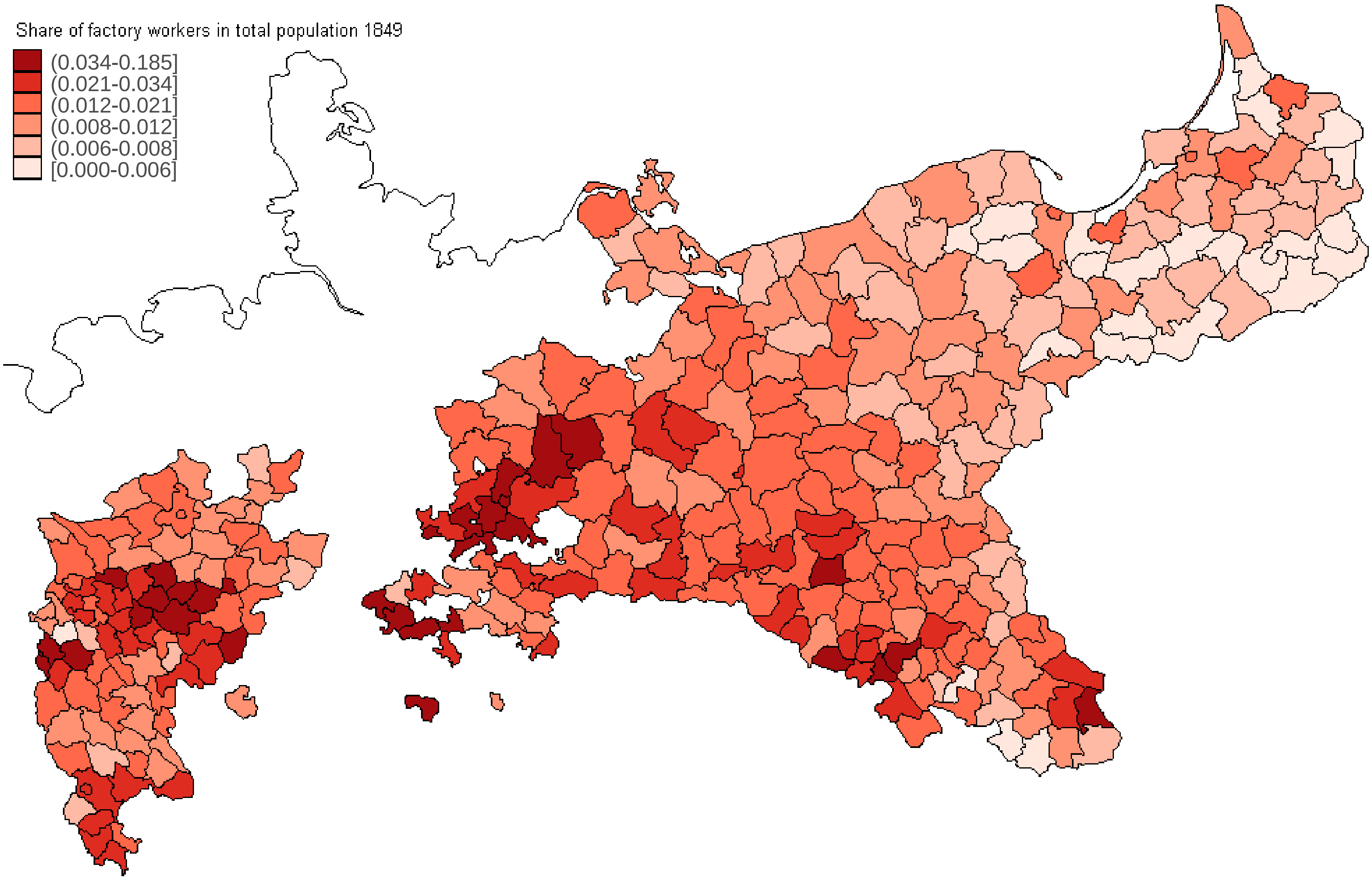
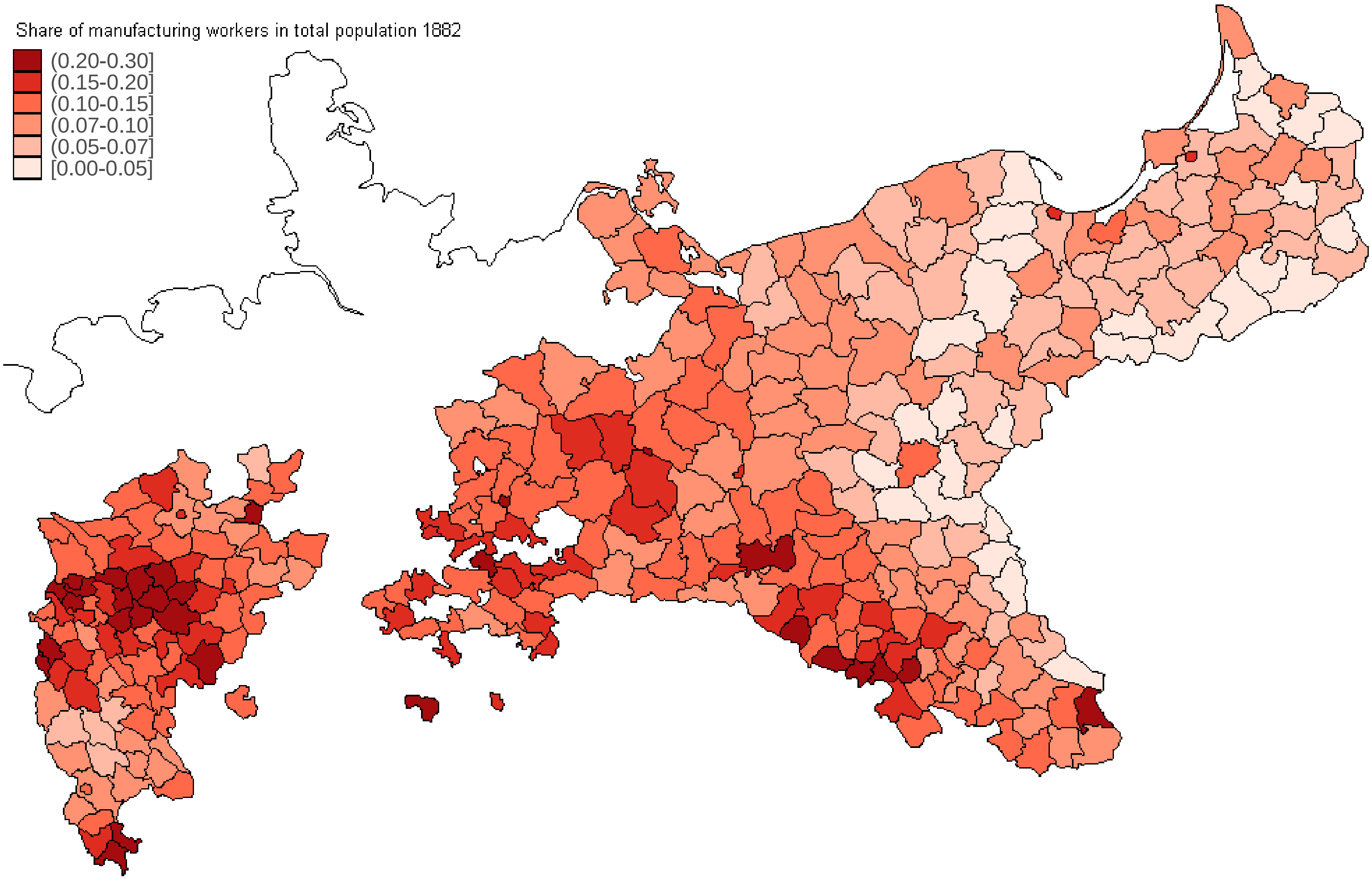
FIGURE A1: FACTORY WORKERS IN THE FIRST PHASE OF THE INDUSTRIAL REVOLUTION IN PRUSSIA 1849



Notes: County-level depiction based on the 1849 Factory Census. The delimiters correspond roughly to the 10th, 25th, 50th, 75th, and 90th percentile of the variable. See Web Appendix A for data details.

FIGURE A2: MANUFACTURING WORKERS IN THE SECOND PHASE OF THE INDUSTRIAL REVOLUTION IN PRUSSIA 1882



Notes: County-level depiction based on the 1882 Occupation Census. The delimiters correspond roughly to the 10th, 25th, 50th, 75th, and 90th percentile of the variable. See Web Appendix A for data details.

TABLE A2: DESCRIPTIVE STATISTICS

	Mean (1)	Std. dev. (2)	Min (3)	Max (4)
Education measures:				
School enrollment rate 1816	0.577	0.201	0.027	0.954
School enrollment rate 1849	0.801	0.117	0.334	0.989
Years of schooling 1849	5.187	1.268	1.528	7.713
Literacy rate 1871	0.839	0.136	0.361	0.985
Share of factory workers in total population 1849:				
All factories	0.018	0.017	0.004	0.185
All factories except metals and textiles	0.009	0.008	0.002	0.072
Metal factories	0.006	0.011	0.000	0.165
Textile factories	0.003	0.007	0.000	0.070
Share of all factory workers in occupied labor force	0.028	0.032	0.003	0.353
Share of manufacturing workers in total population 1882:				
All manufacturing	0.116	0.058	0.022	0.292
All manufacturing except metals and textiles	0.046	0.018	0.010	0.106
Metal manufacturing	0.031	0.033	0.005	0.207
Textile manufacturing	0.039	0.031	0.007	0.226
Share of all manufacturing workers in occupied labor force	0.270	0.134	0.061	0.718
Basic demographic and geographic measures:				
Share of population < 15 years 1849	0.351	0.028	0.228	0.414
Share of population > 60 years 1849	0.060	0.012	0.031	0.093
Share of population < 15 years 1882	0.348	0.031	0.275	0.624
Share of population > 70 years 1882	0.025	0.006	0.010	0.051
County area (in 1000 km²)	0.812	0.450	0.002	2.541
Pre-industrial development:				
Share of population living in cities 1816	0.248	0.187	0.000	1.000
Looms per capita 1819	0.008	0.019	0.000	0.233
Steam engines in mining (per 1000 inhabitants) 1849	0.015	0.086	0.000	1.010
Sheep per capita 1816	0.551	0.439	0.000	2.579
Share of farm laborers in total population 1819	0.095	0.040	0.000	0.241
Public buildings per capita 1821	0.004	0.003	0.000	0.021
Paved streets 1815 (dummy)	0.222	0.416	0.000	1.000
Tonnage of transport ships (in 4000 p) per capita 1819	0.013	0.047	0.000	0.550
Additional demographic and geographic measures:				
Distance to Wittenberg (in 1000 km)	0.333	0.165	0.000	0.731
Share Protestants 1816	0.598	0.399	0.000	1.000
Share Jews 1816	0.012	0.019	0.000	0.098
Year in which annexed by Prussia (divided by 1000)	1.735	0.081	1.608	1.816
Western part	0.281	0.450	0.000	1.000
Polish parts	0.497	0.501	0.000	1.000
Distance to Berlin (in 1000 km)	0.329	0.161	0.000	0.650
Distance to next province capital (in 1000 km)	0.085	0.043	0.000	0.280
Distance to London (in 1000 km)	0.940	0.328	0.416	1.534
Latitude (in rad)	0.909	0.024	0.859	0.972
Longitude (in rad)	0.239	0.084	0.105	0.394
Landownership inequality 1849	0.019	0.020	0.000	0.110

Source: Data for Prussian counties from different censuses; see Web Appendix A for details.

TABLE A3: CORRELATIONS AMONG THE EDUCATION AND INDUSTRIALIZATION MEASURES

		(1) A	(2) B	(3) C	(4) D	(5) E	(6) F	(7) G	(8) H	(9) I	(10) J	(11) K	(12) L
A	School enrollment rate 1816	1.000											
B	School enrollment rate 1849	0.543	1.000										
		(0.000)											
C	Years of schooling 1849	0.981	0.691	1.000									
		(0.000)	*(0.000)*										
D	Literacy rate 1871	0.622	0.671	0.684	1.000								
		(0.000)	*(0.000)*	*(0.000)*									
	Share of factory workers in total population 1849:												
E	All factories	0.119	0.223	0.156	0.329	1.000							
		(0.029)	*(0.000)*	*(0.004)*	*(0.000)*								
F	All factories except metals and textiles	0.214	0.248	0.244	0.343	0.599	1.000						
		(0.000)	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*							
G	Metal factories	0.014	0.072	0.031	0.135	0.775	0.157	1.000					
		(0.805)	*(0.188)*	*(0.570)*	*(0.014)*	*(0.000)*	*(0.004)*						
H	Textile factories	0.017	0.134	0.042	0.180	0.469	0.030	0.071	1.000				
		(0.757)	*(0.014)*	*(0.448)*	*(0.001)*	*(0.000)*	*(0.589)*	*(0.198)*					
	Share of manufacturing workers in total population 1882:												
I	All manufacturing	0.198	0.324	0.245	0.579	0.587	0.308	0.395	0.427	1.000			
		(0.000)	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*				
J	All manufacturing except metals and textiles	0.366	0.397	0.409	0.671	0.480	0.479	0.211	0.264	0.731	1.000		
		(0.000)	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*			
K	Metal manufacturing	0.098	0.192	0.131	0.337	0.505	0.205	0.556	0.082	0.686	0.313	1.000	
		(0.075)	*(0.000)*	*(0.017)*	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*	*(0.136)*	*(0.000)*	*(0.000)*		
L	Textile manufacturing	0.055	0.169	0.081	0.330	0.279	0.080	0.025	0.548	0.705	0.447	0.039	1.000
		(0.320)	*(0.002)*	*(0.138)*	*(0.000)*	*(0.000)*	*(0.143)*	*(0.648)*	*(0.000)*	*(0.000)*	*(0.000)*	*(0.483)*	

Notes: Number of observations: 334. *p* values in parentheses.

Source: Data for Prussian counties from different censuses; see Web Appendix A for details.

TABLE A4: DISTANCE TO WITTENBERG AS AN ALTERNATIVE INSTRUMENT

Dependent variable:	Years of schooling 1849	Share of factory workers in pop. 1849			Literacy rate 1871	Share of manuf. workers in pop. 1882		
		All factories	All except metal+text.	Metal factories		All manufact.	All except metal+text.	Metal manufact.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Years of schooling 1849[a]		1.193***	0.790***	0.222				
		(0.377)	*(0.235)*	*(0.165)*				
Literacy rate 1871						0.384***	0.151***	0.160***
						(0.045)	*(0.016)*	*(0.029)*
Distance to Wittenberg (in 1000 km)	-0.018***				-0.310***			
	(0.005)				*(0.032)*			
Share of population living in cities 1816	-0.018***	0.033***	0.017***	0.007	-0.098***	0.047***	0.031***	-0.003
	(0.004)	*(0.009)*	*(0.005)*	*(0.005)*	*(0.033)*	*(0.014)*	*(0.004)*	*(0.006)*
Looms per capita 1819	0.035*	0.103*	-0.012	0.051	0.573***	0.675**	-0.029	0.041
	(0.019)	*(0.056)*	*(0.024)*	*(0.036)*	*(0.173)*	*(0.284)*	*(0.041)*	*(0.077)*
Steam engines in mining per capita 1849	-0.005	0.049***	0.005	0.039***	0.037	0.148***	-0.005	0.166***
	(0.005)	*(0.009)*	*(0.004)*	*(0.004)*	*(0.071)*	*(0.023)*	*(0.011)*	*(0.019)*
Sheep per capita 1816	-0.0004	-0.002	0.001	-0.002*	0.006	-0.030***	-0.008***	-0.010***
	(0.002)	*(0.002)*	*(0.001)*	*(0.001)*	*(0.015)*	*(0.005)*	*(0.002)*	*(0.003)*
Share of farm laborers in total pop. 1819	-0.008	-0.040	0.005	-0.016*	-0.168	-0.014	0.027	-0.024
	(0.016)	*(0.026)*	*(0.015)*	*(0.009)*	*(0.132)*	*(0.060)*	*(0.020)*	*(0.031)*
Public buildings per capita 1821	1.417***	-2.002***	-1.059***	-0.533*	6.956***	-3.889***	-1.033***	-1.136***
	(0.218)	*(0.629)*	*(0.403)*	*(0.283)*	*(1.818)*	*(0.732)*	*(0.284)*	*(0.426)*
Paved streets 1815 (dummy)	0.002	0.001	0.002	0.0005	0.064***	-0.010	-0.001	-0.003
	(0.001)	*(0.003)*	*(0.002)*	*(0.002)*	*(0.010)*	*(0.007)*	*(0.002)*	*(0.004)*
Tonnage of ships per capita 1819	0.015	-0.041*	-0.010	-0.015**	0.117	-0.020	0.022**	-0.006
	(0.012)	*(0.022)*	*(0.015)*	*(0.007)*	*(0.088)*	*(0.038)*	*(0.009)*	*(0.022)*
Observations	334	334	334	334	334	334	334	334
R^2	0.429	-0.060	-0.401	0.153	0.589	0.603	0.439	0.586
1st-stage *F* statistic	16.31				94.18			

Notes: Instrumental-variable estimates, with years of schooling 1849 resp. literacy rate 1871 instrumented by distance to Wittenberg. Additional controls: share of population < 15 years, share of population > 60 years (70 years in 1882), county area (in 1000 km²), and a constant. Columns (1) and (5) report the first stages for columns (2)-(4) and (6)-(8), respectively. Standard errors (adjusted for clustering by 280 original counties) in parentheses: significance at *** 1, ** 5, * 10 percent. [a] Coefficients multiplied by 100.

Source: Data for Prussian counties from different censuses; see Web Appendix A for details.

TABLE A5: FURTHER ROBUSTNESS SPECIFICATIONS

	First phase of the Industrial Revolution (1849)			Second phase of the Industrial Revolution (1882)		
	All industries	All except metals and textiles	Metal industries	All industries	All except metals and textiles	Metal industries
	(1)	(2)	(3)	(4)	(5)	(6)
(A) Baseline (from Tables 3 and 4)	0.182**	0.124***	0.106*	0.136***	0.069***	0.093***
	(0.080)	*(0.046)*	*(0.058)*	*(0.036)*	*(0.013)*	*(0.025)*
(B) Aggregated to 280 original counties	0.214**	0.142**	0.131*	0.125***	0.073***	0.103***
	(0.093)	*(0.056)*	*(0.067)*	*(0.042)*	*(0.014)*	*(0.030)*
(C) Education	0.186**	0.158**	0.099**	0.075*	0.050***	0.072***
	(0.085)	*(0.066)*	*(0.046)*	*(0.040)*	*(0.012)*	*(0.027)*
Education x Urban 1816	-0.056	-0.073	-0.007	0.078*	0.026*	0.032
	(0.092)	*(0.062)*	*(0.049)*	*(0.044)*	*(0.015)*	*(0.029)*
(D) Education	0.167**	0.121***	0.096*	0.115***	0.065***	0.088***
	(0.075)	*(0.046)*	*(0.051)*	*(0.036)*	*(0.013)*	*(0.026)*
Urbanization 1849	0.036*	0.007	0.023	0.164***	0.031***	0.042
	(0.021)	*(0.006)*	*(0.019)*	*(0.031)*	*(0.011)*	*(0.026)*

Notes: Coefficient on education (years of schooling in 1849, literacy rate in 1871). Dependent variable in 1849: share of factory workers (in the respective industry) in total population. Dependent variable in 1882: share of manufacturing workers (in the respective industry) in total population. Instrumental-variable estimates, with years of schooling 1849 resp. literacy rate 1871 instrumented by school enrollment rate 1816. Included controls: share of population < 15 years, share of population > 60 years (70 years in 1882), county area (in 1000 km²), share of population living in cities 1816, looms per capita 1819, steam engines in mining per capita 1849, sheep per capita 1816, share of farm laborers in total population 1819, public buildings per capita 1821, paved streets 1815 (dummy), tonnage of ships per capita 1819, and a constant. The model in row (C) additionally controls for Urban 1816. "Urban 1816" in row (C) refers to a dummy for counties that contain at least one of the 172 medium and large towns in Prussia in 1816 (see Web Appendix A for details). "Urbanization 1849" in row (D) refers to the share of a county's population living in cities in 1849, defined by the Prussian Statistical Office as having city rights and privileges (which applies for roughly 1,000 Prussian cities). Standard errors (adjusted for clustering by 280 original counties) in parentheses: significance at *** 1, ** 5, * 10 percent.

Source: Data for 334 Prussian counties from different censuses; see Web Appendix A for details.