Railways, Growth, and Industrialization in a Developing German Economy, 1829–1910

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Abstract: This paper studies the average and heterogeneous effects of railway access on parish-level population, income, and industrialization in Württemberg during the Industrial Revolution. We show that the growth-enhancing effect of the railway was much greater in parishes that were larger and more industrial at the outset. However, such early industrial parishes were rare in the relatively poor German state. This might explain why we find small average growth effects, which only increase at the end of the 19th century. Heterogeneity in the impact of the railway thus increased economic disparities within Württemberg and contributed to the state's relatively sluggish growth.

Introduction

Explanations of Germany's rapid industrialization in the mid and late 19th century often point to the railway as the single most important initiator of the country's transition to modern economic growth (Fremdling 1977; Rostow 1962; Ziegler 2012). Importantly, the railway was tightly connected to Germany's heavy industries through backward and forward linkages. Railway construction boosted the demand for iron and steel production, which in turn relied increasingly on coal. At the same time, railways expanded the market for German coal, especially from the Ruhr and Upper Silesia. Thus, the railway was at the heart of a 'leading sector complex' (Fremdling 1977), which drove Germany's industrial take-off (Broadberry, Fremdling, and Solar 2008).

The interplay between the railway and heavy industries arguably favored Germany's central and coal-mining regions, thereby increasing regional economic disparities (Gutberlet 2013). Exploring heterogeneity in the impact of the railway is thus essential for understanding its effect on the spatial distribution of economic activity in Germany. This paper uses rich population and employment data to document average and heterogeneous effects of railway access in the Kingdom of Württemberg during the Industrial Revolution.

There are two reasons why Württemberg is a particularly interesting case for studying regional heterogeneity in the importance of the railway for Germany's industrial take-off. First, Württemberg did not industrialize based on heavy industries, as it lacked coal deposits and did not develop an important iron and steel producing sector. Consequently, the country might have benefited less from the railway–and especially its backward linkages to iron–than Germany's centers of heavy industry (Megerle 1979). Second, regional economic differences within Württemberg grew markedly in the second half of the 19th century.[1] Our finely grained data on the universe of Württemberg's civil parishes (henceforth, parishes)–the state's smallest administrative unit which includes both villages and towns–allow us to evaluate whether the railway benefited especially larger and more industrial parishes and thus increased regional disparities within the Kingdom. In particular, falling transportation costs might have intensified the agglomeration of firms and workers in existing industrial centers (Krugman 1991).

We focus on the short- and long-run effects of the first wave of railway expansion in 1845–54, which connected the capital Stuttgart in the middle of the country with major towns in the east, north, and south. Along the way, 73 of Württemberg's 1,858 parishes gained access to the railway, many of them small and insignificant before the coming of the railway. We consider two sets of outcomes: First, we study population, wages, and housing values. These three variables are linked in spatial equilibrium, as workers move between parishes to arbitrage away differences in real wages.[2] Second, we consider a wide range of industrialization measures, including the

[1] The coefficient of variation of regional income per capita doubled in Württemberg between 1849 and 1907, whereas it remained constant in Prussia (Frank 1993).

[2] Spatial equilibrium implies that negative attributes of a location offset positive attributes. For instance, the canonical Rosen-Roback model of spatial equilibrium between cities studies the trade-off between income,

employment share in industry, the local adoption of steam engines, and firm size. Since our employment data distinguish between 320 sectors, we can also study the effect of railway access on specific industries and specialization within industry.

We document two key results. First, railway access had a positive but small average effect on parish-level population growth in Württemberg. In particular, we find that railway access increased annual population growth by 0.3–0.4 percentage points in 1843–1871. This is considerably smaller than the 1–2 percentage point increase that Hornung (2015) documents for Prussian towns over the same period. The positive effect of railway access on population then increased markedly in Württemberg towards the end of the 19th century. Faster population growth coincided with higher local wages and housing costs as well as a more rapid reallocation of labor towards industrial activities.

Second, we document important heterogeneities in the effect of the railway within Württemberg. The positive economic effects of railway access were much greater in initially larger and more industrial parishes. We show, for instance, that the positive effect on population growth was more than twice as large in parishes that already had a factory in 1832 than in parishes without a factory. Thus, the railway exacerbated regional disparities. This finding is consistent with new economic geography models, which highlight that falling transport costs can concentrate economic activity in larger regions (Lafourcade and Thisse 2011). We also show that the positive effect on industrial employment is largely driven by the textile and machine building industries.

A key challenge for the causal interpretation of our findings is the endogenous location of railway lines. For example, large or growing parishes might have been more likely to gain access

amenities, and housing costs. Given amenities, cities with high nominal wages also exhibit high housing costs, so that utility is the same across all locations. If transport infrastructure improvements increase local wages, for example by increasing market access and thus demand (as in Redding and Turner 2015), workers move to the high-wage location. These population inflows then drive up the price of housing. In spatial equilibrium, we would thus expect the railway to simultaneously increase wages, population, and housing prices.

to the railway than small or stagnant parishes. Railways may then follow economic development rather than causing it (Fishlow 1965). We use three empirical strategies to gauge the causal effect of railway access on spatial economic development in Württemberg.

First, our baseline approach compares changes in economic outcomes of parishes with and without railway access in a differences-in-differences framework. The key identifying assumption of this approach is that economic outcomes in railway and non-railway parishes would have followed the same trend in the absence of the railway. We also estimate event study regressions that allow the effect of the railway to vary over time. Second, we apply semi-parametric methods of the treatment effects literature. These methods require railway access to be a function of observable characteristics only but do not postulate a specific functional form for the outcome variables. Third, we restrict the control group to 'losing' parishes that were the runners-up choice for a given railway line. We show that winning and losing parishes were very similar in their pre-railway characteristics and trends. This lends credibility to our identifying assumptions. Our main findings are robust across all three empirical strategies.

Contribution to the literature. Our paper is closely related to a growing literature that studies the growth effects of railways in the 19th century by comparing areas with access to the railway network to areas without access.[3] Many of these studies document positive effects of railways on urban population growth (Atack et al. 2010; Berger and Enflo 2017; Hornung 2015; Jedwab and Moradi 2016). Recently, Berger (2019), Bogart et al. (2022) and Büchel and Kyburz (2020) have complemented the large literature on urban population growth with evidence on parishes.

Our study contributes to this literature in at least two important ways. First, we consider a broader set of outcome variables. In particular, we study income, wages, and housing values

[3] An influential earlier literature estimates the aggregate social savings of railways (see Fogel (1964) and Fishlow (1965) for seminal works and Leunig (2010) for a critical survey). In important recent work, Donaldson and Hornbeck (2016) estimate the aggregate impact of railways on the US agricultural sector in 1890. Bogart (2018) surveys the economic history literature on transport improvements more generally.

in addition to population.[4] Since population growth often serves as a proxy for economic development (Hornung 2015), it is essential to verify that population increases indeed go hand in hand with increases in local income. Furthermore, we consider various indicators for industrialization, which is again only indirectly captured by population growth. Our finely grained employment data allow us to study the effect of railways on specific industries deemed important for Germany's industrial take-off. In related work, Berger (2019) shows for Sweden that the railway increased industrial employment. However, the study does not differentiate between sectors within industry, as we do. We also study the effect of the railway on the adoption of steam as a core technology of the Industrial Revolution.[5]

Second, our disaggregated data on all parishes in Württemberg allow us to uncover new findings on the heterogeneous effects of railways. In particular, we find that the railway's positive effects on population, income, and industrialization were particularly pronounced in larger and industrial parishes. These findings contribute to a small literature that explores heterogeneity in the impact of railways (Berger 2019; Bogart et al. 2022; Gutberlet 2013; Okoye, Pongou, and Yokossi 2019; Tang 2014). In contrast to our results, Hornung (2015) shows for Prussia that the railway had smaller effects on population growth in larger towns. The fact that Württemberg had very few large towns might explain why our results differ from those of Hornung (2015).[6]

We also apply a different identification strategy than most papers in the literature. In

[4]Berger and Enflo (2017) show for Sweden that house prices today are still higher in towns with early access to the railway. Banerjee, Duflo, and Qian (2020) find moderate positive effects of proximity to the Chinese transport networks on county-level GDP per capita but no effect on per capita GDP growth in 1986–2006.

[5]In related work, Atack, Haines, and Margo (2011) find that access to the railway increased establishment size across US counties between 1850 and 1870, and hence conclude that the railway was an important factor in the rise of the factory. Hornung (2015) finds similar results for Prussia.

[6]Hornung (2015) defines towns as large if they had more than 5,000 inhabitants in 1837. Württemberg had only 14 such towns (out of 1,858 parishes).

particular, we compare population changes of winning and losing parishes,[7] instead of using proximity to the least-cost path or straight line between railway nodes as instrument for actual railway access (as in, for example, Berger 2019; Berger and Enflo 2017; Bogart et al. 2022; Büchel and Kyburz 2020; Hornung 2015). One problem of the IV approach is that least-cost paths are likely to correlate with geography and pre-existing transport networks, thereby potentially violating the exclusion restriction. We show that this problem indeed arises in our context.

Our results also bring together two strands of the literature on Germany's industrialization process that quantify the contribution of railways to economic growth (Fremdling 1977, 1985; Hornung 2015) and study regional disparities during industrialization (Frank 1993; Kiesewetter 2004; Gutberlet 2013). The railway was an important driver of Germany's aggregate economic growth in the 19th century. Yet, its impacts varied strongly across regions, with coal-mining and industrialized regions benefiting most. This might partly explain why in the early 20th century, Württemberg remained poorer than most other parts of Germany (Frank 1993; Mann 2006).

Background

The Kingdom of Württemberg was formed in 1806, emanating from the Duchy of Württemberg. Württemberg was initially part of the Confederation of the Rhine (*Rheinbund*), a confederation of German states under the auspice of the French Empire. After the dissolution of the Rheinbund in 1813, Württemberg first joined the German Confederation (*Deutscher Bund*), created at the Congress of Vienna in 1815, and later became a member of the German Empire, founded in

[7] Greenstone, Hornbeck, and Moretti (2010) use a similar approach to quantify agglomeration spillovers. The authors study the productivity of incumbent plants in counties where a large manufacturing plant opened and take incumbent plants in counties that narrowly lost the competition for the new plant as the control group. In the literature on railways and growth, some papers use unrealized lines in placebo regressions, verifying that the treatment effect for placebo lines is zero (see, for example, Ahlfeldt and Feddersen 2018; Berger and Enflo 2017; Jedwab and Moradi 2016).

1871. It was the third largest state of the German Empire after Prussia and Bavaria (see Online Appendix Figure A-1).

Württemberg's initial conditions for the industrialization process were poor (Boelcke 1973; Megerle 1979). The Kingdom's lack of raw materials, such as coal or ore, impeded the development of heavy industries and made the manufacturing sector's energy production dependent on water or animal power. Württemberg also lacked navigable waterways, and its hilly topography made overland transports time-consuming and expensive. The poor transport infrastructure prohibited the import of much-needed raw materials and limited the selling market accessible to firms. The fragmentation of land ownership in Württemberg led to a mixture of agricultural and industrial employment: small farmers sought additional income outside agriculture, and traders often possessed some livestock and land.

Württemberg's institutional arrangements contributed to its relative economic backwardness (Ogilvie 2004, 2019; Ogilvie and Carus 2014). Dominated by bourgeois wealth holders, Württemberg's parliament pushed for policies that granted far-reaching privileges to guilds and other occupational associations. The rent-seeking activities of these special interest groups stifled economic growth in Württemberg until well into the 19th century.

At the dawn of the Industrial Revolution, the textile sector was Württemberg's most important industry. In 1832, official statistics counted 342 manufactories and factories in Württemberg, of which 142 was in the leather, textile and clothing industry (Feyer 1973).[8] The next largest number was in paper and printing (58), chemicals (37), and food, beverages, and tobacco (32). Most manufactories were still small: Almost a third had at most five workers, and only 21 had 100 workers or more.

The German Customs Union (*Zollverein*), founded in 1834 under Prussian leadership, gave

[8]The terms manufactory (*Manufaktur*) and factory (*Fabrik*) were often used as synonyms at the time, referring to industrial plants that employed relatively many workers or produced relatively large quantities (Gysin 1989).

an important impulse for Württemberg's industrialization process (Gysin 1989). By creating a free-trade area throughout much of Germany, the Union considerably expanded firms' potential selling markets (Keller and Shiue 2014; Shiue 2005). Increasing trade volumes between German states also reinforced plans for a German railway network, which the economist Friedrich List had advocated for Württemberg already in 1824 (Mühl and Seidel 1980).

Yet, it was only in 1843 that Württemberg founded a public railway company, the *Königlich Württembergische Staats-Eisenbahnen*, and began to build a railway network. At this time, railway lines had already been opened in the other larger states of the German Confederation (Bavaria, Saxony, Prussia, Austria, Brunswick, Baden, Hanover). Importantly, Württemberg did not approve and license private railway companies for the construction and operation of its main lines. We might thus expect that railway lines were not only chosen based on their expected profitability and therefore less biased towards parishes with favorable growth perspectives.

The construction of Württemberg's railway network. The expansion of the railway network in Württemberg proceeded in three broad stages (Mühl and Seidel 1980), depicted in Online Appendix Figure A-2. The first stage from 1845 to 1854 saw the construction of the country's central line (*Zentralbahn*), connecting Ludwigsburg, the capital Stuttgart, and Esslingen along the river Neckar. The central line was then extended via the eastern line (*Ostbahn*) to Ulm and via the southern line (*Südbahn*) to Friedrichshafen at Lake Constance. The northern line connected Ludwigsburg and Heilbronn, and the western line (*Westbahn*) connected Württemberg with the neighboring state of Baden and thus to the pan-German railway network. Finally, a bridge over the Danube was completed in 1854, connecting Ulm in Württemberg with Neu-Ulm in Bavaria. The bridge opened a railway corridor from the Dutch harbors to Bavaria.

The second stage, which took place between 1857 and 1886, completed Württemberg's main railway network by connecting all major towns and urban areas. The number of parishes with railway access increased from 73 in 1854 to 350 in 1886. The third stage from 1887 onwards saw the construction of several branch lines that connected the rural area of Württemberg's inland with the main lines. In contrast to the main lines, the branch lines were frequently constructed and operated by private railway companies.

The expansion of the railway network was accompanied by sharply increasing transport volume. Württemberg's public railway company carried 12.52 million tonnes of freight in 1910, up from 0.15 million in 1851 and 2.95 million in 1880. Likewise, the number of passengers increased from just 1,752 in 1851 to 10.04 million in 1880 and 64.65 million in 1910. About 58 percent of the railway's revenue came from freight transport in 1910, 35 percent from passenger transport (see Online Appendix 6).

Württemberg's government determined the main nodes of the railway network but generally not the exact route (Mühl and Seidel 1980). The first Railway Law (*Eisenbahngesetz*) of April 1843, for instance, stipulated that the main line was to connect Stuttgart and Cannstatt in the middle of the country with Ulm, Biberach, Ravensburg and Friedrichshafen in the east and south, Heilbronn in the north, and with Württemberg's border to Baden in the west. The aim was to construct the *shortest* connection between Lake Constance, the access point to Switzerland, and the end points of the navigable waterways Neckar and Danube (Mühl and Seidel 1980).

The government then instructed a railway commission and external experts to develop the exact route for each line. The commission compared competing routes mainly under technical aspects, setting thresholds for the permissible curve radius and railway gradient (Mühl and Seidel 1980). External planners were asked to compare the length, gradient, and cost of alternative routes. Online Appendix 4 describes the planning process for the central line in detail.

In addition to technical aspects, Württemberg's geographical location–squeezed between other German states–influenced and often delayed the construction of the railway network. Towns and villages close to the border were generally disadvantaged (Mühl and Seidel 1980). The shortest route between Horb and Sulz in southwest Württemberg, for instance, crossed the

Prussian territory of Sigmaringen. Württemberg first explored potential by-passes but eventually approached Prussia to get permission for the railway to continue through its territory. The issue was solved with a treaty between Prussia and Württemberg in 1865.

Industrialization until 1907. It was not until the late 19th century that Württemberg's industrialization accelerated markedly. Between 1882 and 1895, employment in industry increased by 24 percent. Textile and metal processing were two of the main drivers of industrial employment growth in Württemberg. The number of industrial firms with at least five employees increased by 86 percent between 1882 and 1895, and employment in these firms more than doubled.

Nevertheless, Württemberg still lagged behind most other parts of Germany at the turn of the 20th century. By 1895, 44.4 percent of all full-time employees in Württemberg were still in agriculture, compared to just 36.2 percent in the German Empire as a whole (Losch 1912). Large industrial firms, equipped with engines and work machines, did not yet dominate. In fact, firms with four workers or less still accounted for half of its industrial employment. The agricultural employment share decreased only slowly and still reached 41.3 percent in 1907.

Importantly, industrialization advanced at different speeds across Württemberg. Online Appendix Table A-1 compares Württemberg's four districts with respect to their estimated national income per capita, agricultural employment share, and urbanization rate. The *Neckarkreis* stands out as the most economically developed and dynamic district. Relative to the German-wide average, income per capita of the *Neckarkreis* increased slightly in the second half of the 19th century, from 111.2 in 1849 to 113.3 in 1907 (Frank 1993). In contrast, relative income of the other three districts plummeted. Württemberg's poorest regions thus participated the least in Germany's spectacular growth performance in the second half of the 19th century. As we will see, heterogeneous effects of the railway contributed to these patterns.

Data

Our panel data cover all civil parishes (*Gemeinden*) in the Kingdom of Württemberg. Parishes are the smallest administrative unit in Württemberg, comprising all towns and villages. We merge a few parishes to take boundary changes into account that occur during the observation period.[9] This leaves us with 1,858 parishes with a median area of 8.6 square kilometers.

Outcome variables. Parish-level population data come from 21 population censuses (Statistisches Landesamt Baden-Württemberg 2008), conducted in the Kingdom of Württemberg between 1834 and 1910.[10] Selected censuses also contain information on other demographic characteristics, such as age structure, place of birth, and marital status.

The total population in Württemberg grew from 1.570 million in 1834 to 1.819 million in 1871 and 2.458 million in 1910. Figure 1 shows the average annual growth rate of parishes in 1834–1910, along with Württemberg's railway network in 1855. The figure documents large variation in population growth, with almost a third of Württemberg's parishes experiencing population decline. Württemberg's poor economic conditions made the Kingdom one of the main origin regions for overseas migration from Germany in the 19th century. More than 337,000 people left Württemberg in 1834–1871 alone (von Hippel 1984). Figure 1 also indicates that population growth was indeed higher in parishes along the railway network.

[Figure 1 about here.]

[9] We digitized parish borders from Kommission für geschichtliche Landeskunde in Baden-Württemberg and Landesvermessungsamt Baden-Württemberg (1972) and use information on border changes from Statistisches Landesamt Baden-Württemberg (2008). Overall, 71 parishes are affected by mergers.

[10] The census years are 1834, 1837, 1840, 1843, 1846, 1849, 1852, 1855, 1858, 1861, 1864, 1867, 1871, 1875, 1880, 1885, 1890, 1895, 1900, 1905, and 1910. We correct a few obvious data errors and interpolate missing population data for parishes in the county of Böblingen in 1867 and the county of Leonberg in 1858.

We digitized data on the average daily wage of day laborers (*ortsübliche Tagelöhne gewöhnlicher Tagarbeiter*) in 1884, 1898, and 1909, taxable income and building tax revenues in 1907, and the fire insurance value of buildings in 1908 (Königliches Statistisches Landesamt 1898, 1910). The wage data, recorded following the Sickness Insurance Law of 1883, distinguish between female and male workers. Taxable income refers to natural persons and equals income net of tax allowances and other deductions. We approximate average housing values from building tax revenues in 1907 and use average fire insurance values as an alternative indicator.[11]

We further digitized employment data from the occupation censuses of 1895 and 1907 (Königliches Statistisches Landesamt 1900a, 1910),[12] which comprise parish-level information on the number of full-time gainfully employed persons (self-employed and dependent) in agriculture, industry, and trade and transport. We also digitized Württemberg's *Gewerbestatistik* for 1829 (various volumes of *Gewerbekataster*, Staatsarchiv Ludwigsburg E 258 VI) and 1895 (Königliches Statistisches Landesamt 1900b).[13] *Gewerbe* includes mining, manufacturing, handicrafts, construction, trade, and transport (excluding railways and post). The data provide information on the number of establishments and their total employment, disaggregated by 3-digit sectors.[14] We use the *Gewerbestatistik* to distinguish between industrial employment in specific industries, measure specialization using the Herfindahl- Hirschman-Index (HHI),[15] and calculate the average number

[11]The building tax was 2 percent of a building's return, and the return was set to 3 percent of a building's market value (Pistorius 1904). We thus approximate the overall building value by dividing tax revenues by 0.02×0.03. We divide the overall building value by the number of buildings to measure a parish's average housing value. Fire insurance covers furniture and other possessions in the house in addition to the property value.

[12]The 1895 occupation census is, to our knowledge, the first that provides employment data at the parish level.

[13]To the best of our knowledge, Württemberg's statistical office did not publish the 1907 edition.

[14]We match the 3-digit industry groups from the 1829 to the 320 groups of the 1895 edition. Employment data of the *Gewerbestatistik* and the occupation census are not directly comparable. The occupation census records employment at the place of residence of each worker, while the *Gewerbestatistik* focuses on the location of plants.

[15]The index is calculated as $HHI_{it} = \sum_{l=1}^{L} (b_{ilt})^2$, where b_{ilt} is parish i's employment share of the (3-digit) industrial sector l in total industrial employment at time t (1829, 1895). The HHI ranges from $1/L$ (if all sectors

of persons employed in an establishment (*Hauptbetrieb*).

Finally, we obtain data on the location of steam engines from archival records (Staatsarchiv Ludwigsburg E 170 Bü 272). Data are available from 1845 to 1869 and include the year of installation and the maximum capacity of each steam engine.

Railway access. We link the panel data on population, sectoral employment, and income with geo-referenced information on parishes and railway construction in Württemberg. Dumjahn (1984) and Wolff and Menges (1995) report the starting and end points of each railway line, the length of the line and its opening date. We use this information to define the nodes of the railway network. We identify parishes as nodes if they served as a network junction or were starting or end points of a railway segment that was constructed without interruption. Data on railway stations in 1911 are published in Königliches Statistisches Landesamt (1911).

Control variables. We take information on the pre-railway share of Protestants from Königliches Statistisches Landesamt (1824). We add data on the location of manufactories in 1832, published in Memminger (1833). Data on the average elevation of parishes come from Bundesamt für Kartographie und Geodäsie (2017). We also add dummies for being located at a river navigable in 1845 and being connected to a paved road in 1848 (Kunz and Zipf 2008).

Empirical Strategy

Treatment and control group

The main challenge for identifying the causal effect of railway access is that parishes were not randomly chosen to be connected to the railway. Table 1 illustrates this selection problem: It compares economic and demographic characteristics of different groups of parishes before the construction of Württemberg's railway network began. Column (1) shows characteristics for the

have the same employment) to 1 (if all employment is concentrated in one sector) railway nodes, Column (2) for other parishes that gained access to the railway in the first stage of the railway expansion, and Column (3) for all other parishes. Columns (5) and (6) restrict attention to the sub-sample of winner and runner-up parishes.

[Table 1 about here.]

Württemberg's government generally chose the largest and economically most important cities–such as the capital Stuttgart–as railway nodes. Nodes had a much higher population than other parishes and were more likely to be located at rivers and to have a manufactory in 1832 (see Column (1) of Table 1). As it is common in the literature, our analysis excludes nodes and focuses on the effect of railway access on parishes that gained access to the railway in the first stage of the expansion (but were not nodes). These are the parishes in the treatment group.

One potential control group is all parishes that did not gain access to the railway in the first stage of the expansion. However, the selection problem carries over–albeit in muted form–to a comparison between railway parishes that were not nodes (Column (2)) and non-railway parishes (Column (3)). Treated parishes were generally larger, situated at lower altitudes, and more likely to have road access than non-railway parishes (Column (4)). Comparisons between the two groups might thus yield biased estimates.

Parts of our analyses thus focus on an alternative control group, consisting of parishes that would have obtained access to the railway if proposed alternative routes had been built. As described above, Württemberg's government first determined the nodes of the network and then instructed a railway commission and external experts to develop the exact route for a given railway. The experts typically came up with several proposals. We use these proposals to identify runner-up parishes, that is, parishes with designated railway access on an alternative line that was eventually not built in the first stage of the railway expansion.

Figure 2 shows the runner-up parishes (crosses), along with the winner parishes (points) and the railway nodes (stars). Colors mark all parishes that under a specific proposal would have received access to the railway. Henceforth, we refer to all potential routes suggested for one line as a 'case'. Overall, there are seven such cases in the first construction stage (see Online Appendix Table A-4 for details). The decision for or against a specific route was mainly based on technical aspects. Political conflicts with neighboring countries also played a role (see the "Background" section). In contrast, local special interest groups had arguably only little influence on the decision process, despite their generally powerful role in Württemberg's politics and society. Their influence was limited by the strong role played by the government (Mann 2006) and external experts (Mühl and Seidel 1980) in the choice of network connections (Online Appendix 7 discusses these points in great length).

[Figure 2 about here.]

We rely on runner-up or losing parishes to identify a valid counterfactual for what would have happened to railway parishes had they not gained access to the railway in the first stage of the railway construction. Runner-up parishes should share many pre-treatment characteristics with parishes in the treatment group, as both groups were candidates for railway access in the first stage. In fact, many of the proposed lines that were initially not realized were built later.

Columns (5) to (7) of Table 1 provide support for our empirical strategy. Differences in pre-treatment characteristics decrease considerably when we compare winner (Column (5)) and runner-up parishes (Column (6)).[16] This holds, in particular, for parishes' access to roads and rivers, which differed greatly between railway and non-railway parishes but not between winner and runner-up parishes. In fact, none of the mean differences between winners and runners-up

[16]Nine of the railway parishes in Column (2) are not among the winner parishes in Column (5). These are parishes that would have been connected to the railway under all proposals (Asperg, Baindt, Ölbronn, Tamm) or parishes on the line Ravensburg-Friedrichshafen (Berg, Eschach, Hirschlatt, Meckenbeuren, Taldorf), for which no alternative route was proposed. On the other hand, five parishes are counted twice, as they were among the winning parishes in two different cases (Obertürkheim, Schweinhausen, Ummendorf, Unteressendorf, Wolpertswende).

is statistically significantly different from zero (Column (7)) (although this may also be due to the small sample size). If anything, winners appear to be smaller and less industrialized than runners-up before the coming of the railway.

Distinguishing, in contrast, between parishes that are and are not located on a straight-line corridor between two railway nodes does not balance pre-treatment characteristics. Online Appendix Table A-10 shows that parishes on a straight-line corridor (or least cost path) were much more likely to have been connected to pre-railway transport networks. The significant differences in pre-treatment observables suggest that also unobservables may differ between groups. Using location on a straight-line corridor or least-cost path as an instrument for railway access, as done in most of the related literature, may produce biased estimates.[17]

Empirical specification

Panel fixed effects regression. We begin by estimating the effect of railway access using a standard two-way fixed effects regression, which we describe in the following for the comparison of winner and runner-up parishes. Let $D_{ij,1855}$ be a binary treatment group indicator that indicates whether parish i along case j (a case comprises all potential routes suggested for one line) was connected to the railway by 1855, and let y_{ijt} be an outcome variable in year t. Our baseline specification is:

$$\begin{aligned} y_{ijt} &= \theta_i + \lambda_t + \beta D_{ij,1855} + \gamma(D_{ij,1855} \times 1(\tau \geq 0)_{jt}) + \varepsilon_{ijt} \\ &= \theta_i + \lambda_t + \beta D_{ij,1855} + \gamma Line_{ijt} + \varepsilon_{ijt}, \end{aligned} \quad (1)$$

where θ_i and λ_t are parish and year fixed effects, respectively. τ denotes years but is normalized so that for each case, the railway line's opening year is $\tau = 0$. $1(\tau \geq 0)_{jt}$ is thus a dummy equal

[17] Appendix Table A-11 shows IV estimates of the effect of railway access on population. The IV estimates are indeed slightly larger than the corresponding panel estimates in Table 2, Columns (4) and (5).

to one for all years after case j's railway line was opened. Opening years vary between 1843 and 1855.[18] The treatment variable $Line_{ijt}$ thus indicates whether a parish in the treatment group has railway access in year t.

The coefficient of interest (γ) captures mean shifts in outcome variables of treatment relative to control parishes after the railway line was opened. For most outcome variables (sectoral employment, specialization, firm size, adoption of steam), we have data for one year before (typically 1829) and one year after the first stage of the construction of the railway network (typically 1895/1907). This renders equation (1) a standard differences-in-differences (DiD) equation with two groups (winners and runners-up) and two periods (before and after treatment). For population, we use data for 21 census years between 1834 and 1910.[19]

Identification of the impact of the railway in equation (1) rests on the assumption that parishes that gained access to the network until 1855 would have developed similarly to other parishes in the absence of railway construction. The similarity of treated and control parishes in their pre-railway outcomes (see Table 1) lends credibility to the assumption. We probe the robustness of our estimates to the inclusion of year-by-case fixed effects and test for differences in pre-treatment trends in our analysis of the effect of railways on population.

Event study analysis. Specification (1) tests for a mean shift in our outcome variables. In our population analysis with many periods, the model implicitly assumes that any effect occurs

[18]Our baseline specification abstracts from within-line differences in opening years and takes the first year in which a segment of the line was opened as the opening year of the entire line. This should reduce potential anticipation effects. In a robustness check, we instead use parish-specific opening years and come to similar conclusions. This is to be expected, as most segments and stations of a line open within just a short time period.

[19]We then consider a DiD setting with variation in treatment timing. In our application, most parishes remain untreated, as they did not receive railway access in the first construction phase. Thus, comparisons between treated and untreated units (rather than between earlier and later treated units) contribute the most to the treatment coefficient estimate, as we verify using the decomposition developed by Goodman-Bacon (2021).

immediately and then remains constant over time. In additional event study regressions, we relax this assumption and allow the effect to vary with the time since treatment by estimating:

$$y_{ijt} = \theta_i + \lambda_t + \ddot{\beta} D_{ij,1855} + \sum_{k=-4}^{13} \gamma_k (D_{ij,1855} \times 1(\tau = k)_{jt}) + \sum_{k=-4}^{13} \delta_k 1(\tau = k)_{jt} + \ddot{\varepsilon}_{ijt}. \qquad (2)$$

Coefficient γ_k for $k \geq 0$ corresponds to the difference in log population between treated and runner-up parishes k observation periods after the railway line was opened.[20] The difference is expressed relative to four periods before the line was opened (that is, we normalize γ_{-4} to zero).[21] We estimate the specification for $-4 \leq \tau \leq 13$, as the sample is balanced for these periods. Specification (2) also tests for differences in trends between treated and control parishes in the periods before the railway line was opened.

Semi-parametric estimates. We can interpret the parameter γ in equation (1) as an estimate of the average treatment effect on the treated (ATT). However, this interpretation hinges on the linearity assumption present in equation (1). In an alternative strategy, we leave the data-generating process of the outcome variables unspecified and estimate the ATT by inverse probability weighting (IPW) (see Online Appendix 9 for technical details). IPW estimates the ATT by comparing *weighted* outcome means of parishes with and without railway access. Intuitively, IPW places more weight on observations in the control group that–given their covariates–had a high probability of being treated in the first place.

The key assumption for IPW to yield the causal effect of interest is that conditional on covariates, potential outcomes are independent of railway access. In contrast to DiD, IPW

[20] We focus on periods rather than years since treatment, as we do not have annual population data and the length between two census years varies over time (see Footnote 10). Consequently, we observe parishes at different years since treatment, depending on the year they obtain railway access.

[21] Historical accounts suggest that railway parishes already experienced a population increase just before the railway line opened, as construction workers gathered in the parishes. That is why we express our estimates relative to the first period in our sample–rather than relative to the period just before the opening of the line.

does not require data on the pre-treatment period, which we lack for agricultural employment, income, wages, and housing values. In a robustness check, we use the inverse probability weighted regression adjustment (IPWRA) approach, which has the advantage that either the outcome or the treatment model has to be correctly specified, not both (see Online Appendix 9). Estimating cross-sectional models by OLS rather than IPW or IPWRA yields very similar results.

Our covariates in IPW and IPWRA include log population and log population density in 1834, the share of protestants in 1821, a binary variable that indicates a running manufactory or factory in 1832, industrial employment per 100 persons in 1829, the average elevation in meters, and two binary variables that indicate access to a paved road in 1848 and a waterway navigable in 1845 (see Table 1 for summary statistics). We also add case fixed effects as controls.

Average Effects of the Railway: Württemberg-wide Results

Population growth

Table 2 presents panel regression estimates of the effect of obtaining railway access in the first construction phase on population. Column (1) reports results from our baseline specification (1) with year and parish fixed effects, restricting the sample to winner and runner-up parishes. The regression suggests that railway access increased the population of winning parishes by 0.117 log points (relative to losing parishes). This effect is statistically significant, with a standard error of 0.033. Specification (2) adds year-by-case fixed effects, which control for case-specific time trends. Specification (3) adds a binary control variable that switches to one once a parish in the control group obtains railway access in the second or third construction phase. The estimated treatment effect increases only slightly to 0.136 (s.e. of 0.032) and 0.123 (s.e. of 0.026), respectively. Inference based on Conley standard errors, which account for potential spatial and serial correlation, yields very similar results (see Online Appendix Table A-8 for details).

[Table 2 about here.]

Specifications (4) to (6) re-estimate the regressions on the full sample of parishes. At 0.172 (s.e. of 0.024), the baseline estimate for the full sample is larger than the corresponding estimate for the winners versus runners-up sample. This is consistent with the notion that in the full sample, the control group includes many small and remote parishes with unfavorable growth perspectives. The treatment effect in Column (4) is thus likely upward biased. The difference in the treatment effect estimated for the two samples vanishes when we add year-by-county fixed effects (Column (5)), which account for time varying differences between Württemberg's 64 counties (*Oberämter*).[22] Controlling also for later railway access hardly affects the estimated treatment effect (Column (6)). Although the full-fledged panel model delivers similar results for both samples, we focus on the more comparable winners versus runners-up sample in what follows. This is because we cannot estimate panel models for the subset of outcomes that we observe only after the first stage of the railway expansion.

The event study analysis allows the effect of railway access on population to vary with time since treatment. Figure 3 shows the estimated differences in log population between winner and runner-up parishes, relative to the baseline difference four periods before the treatment. Point estimates for the pre-treatment periods are very close to zero and statistically insignificant. Population in winning and losing parishes thus evolve in tandem before the arrival of the railway. At the time of the treatment, the point estimate jumps up to 0.036. The difference in log population then gradually widens with time since treatment. Thirteen periods after treatment or after about 50 years,[23] population in winner parishes is, on average, 0.248 log points larger

[22]For instance, the foundation of the German Customs Union in 1834–and its successive enlargement until 1888–might have had different effects on Württemberg's border and inland regions (see Ploeckl 2013, for an analysis of spatial heterogeneity in the impact of the customs union in the neighboring state of Baden). The treatment effect changes little (to 0.130, s.e. of 0.023) if we also add interactions between year dummies and the pre-railway covariates, shown in Table 1.

[23]Depending on the year a parish obtained the railway, thirteen periods after treatment correspond to slightly different numbers of years. This is because the time between two censuses–and thus the length of a period–varies

than in runner-up parishes. This corresponds to an increase in *annual* population growth of about 0.4 percentage points.

[Figure 3 about here.]

Several additional results for the impact of the railway on population and demographic change are shown in online appendices. Online Appendix 11 documents that semi-parametric IPW and IPWRA yield results that are almost identical to the event study estimates. This is reassuring for our subsequent analyses of wages, income, and housing values, which are based on cross-sectional estimates only due to the lack of pre-treatment data. Online Appendix 12 presents event study and semi-parametric estimates for the full sample, which are similar to those for the winners versus runners up sample.

Online Appendix 13 presents evidence that the railway increased parish-level population by attracting immigration rather than increasing fertility, in line with earlier results for Prussia (Hornung 2015). Workers arguably moved into railway parishes in search of higher wages and employment opportunities in industry, consistent with spatial equilibrium models.[24]

Online Appendix 14 shows for the full sample of parishes that gaining access in the second stage from 1857 to 1886 also boosted population.[25] However, the effect for the second stage

between three and five years.

[24]Workers might also have moved to railway parishes to commute into larger railway nodes for work. Unfortunately, we cannot test this hypothesis as we lack data on commuter flows. However, the positive effects of railway access on industrial development, wages, and income, which we document below, strongly suggest that commuting was at least not the only motive for new dwellers to move into railway parishes.

[25]The positive effect of later railway access does not carry over to the winner versus runner-up sample (see Online Appendix 14). Runner-up parishes that gained access in 1857–86 did not grow faster than runner-up parishes that remained without access by 1886. This might be because runner-up parishes are located along alternative routes between major towns that had already been connected to the network in 1845–54. Building initially unrealized alternative routes between these towns did not boost population along the way, probably because the winning lines were already in operation.

is somewhat smaller than for the first. This is not surprising, as the most important lines, especially for transit passengers and freight, had already been built in the first construction phase. The difference in effect size also cautions against extrapolating from the effects of the main railway lines to the effects of the railway network at large.

We also study whether the positive effects near the railway came at the expense of locations in middle distances. Estimates from local polynomial regressions yield little evidence for localized displacement effects in our finely grained spatial data. Online Appendix 15 discusses these results in more detail.

Income, wages and housing values

We next analyze the effect of railway access on income, wages, and housing values. In spatial equilibrium, we would expect population increases to go hand in hand with increases in income and housing values. We focus on the more comparable parishes in the winners versus runners-up sample and report qualitatively similar findings for the full sample in Online Appendix 19.[26]

We first consider the effect of railway access on the average daily wage of day laborers in 1884, 1898, and 1909, distinguishing between females and males (see Columns (1) to (6) in Table 3). Estimates from IPW (Panel A), IPWRA (Panel B), and OLS (Panel C) models all suggest that railway access had a statistically significant positive wage effect. IPW estimates indicate that access increased female day laborer wages by 7.0, 9.7, and 8.2 *Pfennig* in 1884, 1898, and 1909, respectively. This corresponds to an increase of 6.3, 8.3, and 4.9 percent, respectively, relative to the control group average. The relative effect is somewhat lower for male day laborers, ranging

[26] In the following, we do not control for later railway access, as we are interested in the effect of getting the railway early. In fact, we would arguably induce selection bias in our analysis if we were to focus only on runner-up parishes that never gained railway access as the control group. This is because these parishes are likely to be the marginal ones among all the runner-up parishes. Nevertheless, our results reported in the following also hold if we control for later railway access (results can be obtained from the authors upon request).

from 3.3 to 5.5 percent. These results suggest that railway-induced industrialization benefited also the working class.[27] The higher treatment effect for females translates into a statistically significant lower gender wage gap in winning parishes of 2.0 and 1.7 percentage points in 1884 and 1898, respectively (from a baseline of 32.8 percent, see Online Appendix Table A-9 for details). The lower gender wage gap is consistent with the idea that falling transport costs induced mechanization, which in turn increased the relative productivity of women by reducing the importance of human strength in production (Goldin 1990; Galor and Weil 1996).

[Table 3 about here.]

We next consider taxable income per capita in 1907. The IPW estimate suggests that railway access increased the annual taxable income in winning parishes by 48.3 *Mark* or 13.2 percent (see Column (7) of Table 3). The relative increase in taxable income is thus comparable to the increase in day laborer wages. Finally, Columns (8) and (9) of Table 3 show the treatment effect on the average building value in 1907 and the fire insurance value in 1908, respectively. Railway access increased the average building value by 1,388.4 *Mark* or 44.1 percent (IPW estimate in Panel A). The increase in insurance value per building is of comparable size.

Industrial development and sectoral employment

We next study the effect of railway access on structural change from agriculture to industry, a core characteristic of the Industrial Revolution. We also provide evidence on specific sectors identified in the literature as drivers of Germany's industrialization process. We again focus on the winners versus runners-up sample and report qualitatively similar results for the full sample in Online Appendix 19.

[27] An alternative interpretation of this result is that the railway-induced decrease in travel costs fostered overseas emigration, decreasing local labor supply. Karadja and Prawitz (2019) have recently shown that mass emigration to the US increased wages of low-skilled workers in Sweden. In our context, however, railway access increased net migration into local parishes, so that a demand-based explanation seems more plausible.

We first study the effect of railway access on various measures of industrial development. Panels A and B of Table 4 present results from IPW and IPWRA estimations and Panel C from DiD regressions. Columns (1) to (4) show that railway access accelerated the transition from agriculture to industry. The IPW estimates in Column (1) of Panel A imply that railway access increased industry employment in winning parishes by 2.8 employees per 100 persons or 18.9 percent relative to the 1895 average in losing parishes. The percent increase in industrial employment in 1907 (Column (2)) is similar to that in 1895. Increased industrial employment came at the expense of agricultural employment (Columns (3) and (4)). The IPW estimate implies that railway access decreased the number of full-time employees in agriculture by 3.7 employees per 100 persons in 1895, or 15.8 percent relative to the control group average. This negative effect increases to 6.7 employees or 25.5 percent in 1907.[28] The results of the IPWRA (Panel B) and DiD regressions (Panel C) are almost identical to the IPW estimates.

[Table 4 about here.]

Falling transport costs are widely believed to have increased optimal establishment size by integrating markets and expanding market size. The ensuing competitive pressures, so the argument, forced firms to increase productivity through the division of labor and mechanization and thus promoted the rise of factories (Atack, Haines, and Margo 2011). In line with this argument, we find that railway access increased establishment size by between 0.221 and 0.228 log points compared to losing parishes (Column (5) of Table 4).

We also find strong evidence that the railway accelerated local technological change. IPW/ IPWRA estimates suggest that railway access increased the likelihood of having at least one

[28]The IPW/IPWRA estimates seem to suggest that railway access decreased the total number of full-time employees per 100 persons, as the employment decline in agriculture is larger than the increase in industry. Unreported estimations show, however, that the total employment effect of railway access is statistically indistinguishable from zero, as access also increased employment in trade and the public sector.

steam engine in operation in 1867 by more than 20 percentage points (from a baseline of 25.3 percent in losing parishes) and the total steam power installed by 14.5 horsepower per 1,000 persons (from a baseline of 2.2). Railway access lowered the costs of coal shipments sufficiently for steam-powered industrial growth to happen outside the coal mining regions (Gutberlet 2014).

Our unusually disaggregated data allow us to study the employment effect of railways for specific industries. Table 5 shows results from IPW (Panel A), IPWRA (Panel B), and DiD (Panel C) models. Column (1) suggests that railway access boosted the local textile industry, Württemberg's most important industry at the dawn of the Industrial Revolution. Average 1895 employment in the textile sector (excluding fiber production) was 4.3 employees per 100 persons in winning parishes but only 2.0 employees in losing parishes. In contrast, textile employment was virtually identical in the pre-treatment period 1829 (1.9 and 2.0 in winning and losing parishes, respectively). The railway expanded the market for textile exports and enabled coal to be transported to power steam engines. In fact, the textile industry used 37.8 percent of the steam power installed in Württemberg in 1875 (Kaiserliches Statistisches Amt 1879).

In contrast, the railway did not increase employment in the coal, iron, and steel industry, which played a core role in Germany's growth take-off during the third quarter of the 19th century (Broadberry, Fremdling, and Solar 2008; Ziegler 2012). If anything, the effect is negative (though not statistically significant, see Column (2)). This result might seem surprising, as railways boosted the German coal, iron, and steel production (Fremdling 1985). However, Württemberg lacked coal deposits. After the railway markedly decreased transport costs, Württemberg's steel and iron producers were no longer able to compete with the cheaper producers located in the resource-rich Ruhr and Saar regions. Consequently, Württemberg's share in the German pig iron and steel production plummeted from 2.6 percent in 1850 to 0.2 percent around 1895 (von Hippel 1992). Online Appendix 16 documents and discusses the decline of iron producers across Württemberg between 1834 and 1895 in greater detail.

[Table 5 about here.]

Column (3) shows that railway access strongly increased employment in the machine and instrument building industry (by about 0.5 employees per 100 persons from a baseline of 0.1 employees), which was an important driver of economic growth in Germany both during the earlier and later stages of the Industrial Revolution. The drive towards mechanization and the expansion of the railway were pivotal for the rise of Württemberg's machine and instrument industry since the mid-19th century (von Hippel 1992). In fact, Württemberg's largest industrial company at the time, the *Maschinenfabrik Esslingen*, was founded in 1846 to produce locomotives for Württemberg's public railway company.[29] Since Württemberg's machine industry was export-oriented, it also benefited from the falling transport costs brought about by the railway.

The late 19th century saw the rise of the electronic and chemical industry in Germany, which gradually replaced the heavy industry as the leading sector in Germany's industrialization process. However, both industries were still small in Württemberg in 1895, counting 821 (electronic) and 2,232 (chemical, excluding pharmacies) employees in the entire state. Columns (4) and (5) show that railway access is positively associated with employment in the two industries, but the estimates are small and not statistically significant.

Finally, Column (6) in Table 5 reports evidence that the degree of specialization within industry is lower in winning than in losing parishes. However, the estimates are imprecise and not statistically significant at conventional levels.

Heterogeneous Effects of the Railway

This section tests whether the effects of gaining railway access in the first construction phase were larger for parishes that already had a manufactory in 1832 and for those with above-median

[29]Esslingen is, however, a railway node and thus excluded from the analysis.

population in 1843,[30] in line with arguments in Gutberlet (2013) and Ziegler (2012). As the railway decreased transport costs, we might expect that agglomeration forces drew industrial economic activity to the more populous centers (Krugman 1991). Consequently, these centers experienced a disproportionate increase in population and industrial employment. Regional agglomeration drove up nominal wages but also led to higher housing prices (for example Südekum 2008).[31] Since the analyses are demanding on the data, we focus on the full sample of parishes. Results based on the winners versus runners-up sample are qualitatively similar.

Table 6 studies heterogeneity in the effect of railway access on population. We estimate DiD specifications with parish and year-by-county fixed effects. Since the event study analysis has shown that the treatment effect grows over time, we estimate a linear trend break instead of a constant treatment coefficient (Goodman-Bacon 2021). The linear time break specification interacts the treatment dummy $Line_{ijt}$ in equation (1) with the difference between year t and the year a line was opened (plus one). We focus on a panel setup with a trend-break treatment rather than the event study model to reduce complexity. The estimate in Column (1) implies that railway access increased *annual* population growth by, on average, 0.6 percentage points.

[Table 6 about here.]

The remaining specifications add interactions between the trend break and dummies for having a manufactory in 1832 and above-median population in 1843. Column (2) shows that

[30] We focus on population in the main locality in case a parish has several localities (*Wohnplätze*). We expect effect heterogeneity to be larger by manufactory location than by population size. Outside the railway nodes, little more than 5 percent of the parishes had a manufactory in 1832. The manufactory dummy thus singles out Württemberg's few existing industrial centers. Of course, these centers had, on average, also higher population.

[31] Krugman (1991) abstracts from land scarcity and differences in housing prices. Living costs are then lower in agglomerations, as competition drives down manufacturing prices. However, this prediction is in contrast with the empirical evidence. Südekum (2008) shows how Krugman's original model can be extended to feature higher housing costs in the industrial core.

the positive effect of railway access on population is more than twice as large for parishes that already had a manufactory in 1832 (1.2 percentage points relative to a baseline effect of 0.5 points for parishes without a manufactory). This is consistent with the prediction that industrial centers particularly benefited from the railway-induced increase in market access. Moreover, the effect of railway access on annual population growth is 0.5 percentage points larger in bigger than in smaller parishes (Column (3)). Thus, the railway reinforced pre-existing population differences. This finding is in line with recent evidence for England and Wales (Bogart et al. 2022).

[Table 7 about here.]

Columns (1) to (5) of Table 7 tests for heterogeneity in the effect of railway access on wages, income, and housing values. Panel A reports average, Panels B and C heterogeneous effects. We interact the treatment dummy with the relevant parish characteristics, which we also include as controls in our (cross-sectional) regressions. As expected, the results mirror our findings for population. We find that the positive effects of railway access on wages, income, and housing values are two to three times larger for parishes that already had a manufactory in 1832 (Panel B of Table 7), although differences in effect size are relatively imprecisely estimated, especially for income and building values. Effect heterogeneity by population (Panel C) is also sizable but tends to be smaller than by manufactory location.

Columns (6) to (9) of Table 7 studies heterogeneity in the effect of railway access on industrial development, using panel regressions. We find that railway access had much stronger positive effects on industrial development in parishes that had a manufactory in 1832 (Panel B). For instance, the estimated effect on industry employment in 1895 is more than twice as large for parishes with a manufactory than for those without one (12.2 versus 5.2 employees per 100 persons). Likewise, the effect of railway access on establishment size is three times larger in manufactory parishes. Effect heterogeneity is even more pronounced in the adoption of steam.[32]

[32]In fact, all manufactory parishes that gained railway access by 1855 had a steam engine installed by 1869

Railway access also had stronger positive effects on industrial development in larger than in smaller parishes (Panel C). Overall, the railway boosted industrial development especially in existing industrial centers, thereby increasing the concentration of industrial activity.

Online Appendix 17 documents significant effect heterogeneity also by railway line. Parishes along the eastern and northern lines, which served Württemberg's densely populated Neckar basin, benefited considerably more from the railway than parishes along the southern line, which served the sparsely populated southeast. This finding is consistent with our result that the railway benefited disproportionally larger and more industrial parishes. These parishes were concentrated in the Neckar basin already before the coming of the railway (Feyer 1973).

Discussion and concluding remarks

This paper has provided a comprehensive analysis of the average and heterogeneous effect of railway access on local growth and industrialization in Württemberg during the Industrial Revolution. Figure 4 summarizes our key findings. It depicts differences in log population between railway and non-railway parishes in 1834–1910, both for average railway parishes and for those with a manufactory in 1832. As a point of comparison, we also show how differences in population would have evolved had railway access increased annual growth by 1-2 percentage points, as was found for Prussian towns (Hornung 2015).

[Figure 4 about here.]

The figure illustrates that our estimates for population growth in Württemberg are considerably smaller than earlier estimates for Prussia. Blue dots show that initially, parishes that gained access to the railway in the first construction stage grew only modestly faster than parishes that did not. If we consider the period until 1871, as Hornung (2015) does, railway access increased annual parish-level population growth in Württemberg by just 0.3 percentage points. In light

(while none of them had in 1846).

of the core role ascribed to the railway in Germany's industrialization process (Fremdling 1977; Ziegler 2012), the comparably small growth effects might partly explain why Württemberg was still relatively poor by German standards in the early 20th century. The growth-enhancing effect of the railway was simply larger in other parts of Germany.

Why did Württemberg benefit less from the railway than Prussia? A first explanation is the belated construction of Württemberg's railway network and its limited length. In Prussia, 21 railway lines were built in 1838–1848, connecting major cities such as Berlin and Hamburg or Magdeburg and Leipzig. In contrast, Württemberg's railway network was limited to short sections around Stuttgart in 1848. This delayed construction of the railway network has been put forward as a potential cause for Württemberg's late industrialization (Naujoks 1982).

Württemberg's railway network then gradually expanded in the second half of the 19th century. By 1868, the density of the railway network was higher in Württemberg than in Prussia (see Online Appendix Figure A-4 for a comparison of network density in Bavaria, Prussia, and Württemberg in 1848–1903). This might explain why the growth effects of early railway access increased over time, as also shown in Figure 4. Parishes along the main railway lines increasingly benefited from the growing network's positive externalities.

However, positive network externalities were presumably smaller in Württemberg than in Prussia, as the latter had a much larger network. Although the railway networks of the different German states were connected, railway administrations were not unified before 1920. This caused significant frictions in the railway traffic between German states, as timetables lacked coordination and price systems differed even after the foundation of the German Empire in 1871 (Ziegler 2012). Without a comprehensive integration of the German railway network, positive externalities were presumably the largest in the dominant Prussian network.

Our finding of strong heterogeneity in the effect of railway access provides a second explanation for why we observe small average growth effects in Württemberg. Figure 4 illustrates that the effect of railway access on population growth was much stronger in parishes that had a manufactory in 1832. For them, growth effects were well within the 1–2 percentage points range reported for Prussia. Yet, only very few parishes in Württemberg had a manufactory already in the pre-railway era. This relative backwardness might have limited the railway's overall growth effect. Württemberg lacked the industrial and coal-mining regions that benefited most from the interplay between railway and heavy industries in Germany (Gutberlet 2013; Ziegler 2012).

The lack of coal limited backward linkages from the railway (Megerle 1979), which were decisive for the dramatic growth of Prussia's coal, iron and steel sector. Württemberg's iron producers could not compete with the cheap imports of coke pig iron from the Ruhr and Saar region as transport costs decreased. Hence, Württemberg's share in the German iron and steel production plummeted in the second half of the 19th century, while Prussia's share increased.

Our finding of significant effect heterogeneity is also important in its own right. The railway was not only an essential driver of Germany's industrialization process. It also increased regional economic disparities between and within German states. This aspect remains under-explored in the literature on the railway's impact on economic growth in 19th century Germany. More generally, our findings show that investment in transportation infrastructure can have markedly different effects on growth and development, depending on the specific local conditions. A better understanding of this heterogeneity can increase the effectiveness and efficiency of infrastructure investments also in contemporary contexts. Our findings caution that transport infrastructure improvements might deepen regional inequality, often against the intention of policymakers.

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Table 1: Group comparison of pre-treatment characteristics

	Full sample				Winners versus runners-up		
	Nodes	Railway parishes	Non-railway parishes	Difference (2) - (3)	Winner parishes	Runner-up parishes	Difference (5) - (6)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Pop. 1834 (log)	8.379	6.801	6.390	0.411	6.740	6.927	-0.187
	(1.464)	(0.642)	(0.702)	[0.091]	(0.662)	(0.715)	[0.116]
Pop. density 1834 (log)	5.628	4.455	4.278	0.178	4.452	4.571	-0.119
	(0.753)	(0.655)	(0.604)	[0.079]	(0.678)	(0.603)	[0.105]
Protestants 1821 (share)	0.730	0.613	0.617	-0.004	0.621	0.673	-0.052
	(0.379)	(0.484)	(0.469)	[0.061]	(0.482)	(0.452)	[0.077]
Manufactory dummy 1832	0.583	0.082	0.053	0.029	0.088	0.172	-0.084
	(0.515)	(0.277)	(0.223)	[0.029]	(0.285)	(0.379)	[0.058]
Ind. employment per 100 persons 1829	12.953	8.793	7.730	1.063	8.930	9.568	-0.637
	(4.087)	(3.611)	(4.320)	[0.560]	(3.651)	(4.176)	[0.664]
Average elevation (in m)	391.685	406.572	496.470	-89.898	418.102	411.113	6.989
	(120.070)	(136.975)	(155.942)	[20.229]	(145.237)	(138.093)	[23.399]
River dummy	0.417	0.148	0.075	0.072	0.175	0.131	0.044
	(0.515)	(0.358)	(0.264)	[0.035]	(0.384)	(0.339)	[0.059]
Road dummy	0.917	0.820	0.480	0.340	0.807	0.778	0.029
	(0.289)	(0.388)	(0.500)	[0.065]	(0.398)	(0.418)	[0.068]
Observations	12	61	1,785		57	99	

Notes: The table shows average values of pre-treatment characteristics for nodes (Column (1)), railway parishes (Column (2)), and non-railway parishes (Column (3)), 'winners' (Column (5)), and 'runners-up' (Column (6)). Column (4) shows the mean difference in pre-treatment characteristics between railway and non-railway parishes and Column (7) the mean difference between winners and runners-up. Nodes are defined as parishes that are either starting or end points of a railway segment or serve as network junctions. Railway parishes obtained railway access in the first construction stage 1845–1854 (but are not nodes). Non-railway parishes did not obtain railway access in the first construction stage. Winners are parishes that obtained railway access in the first construction stage (but are not nodes). Runners-up are parishes that would have obtained railway access in the first construction stage if unrealized alternative routes had been built. Standard deviations are in parentheses (Columns (1)–(3) and (5)–(6)). Standard errors of a two-sided mean difference t-test are in brackets (Columns (4) and (7)).

Sources: Population in 1834 is from Statistisches Landesamt Baden-Württemberg (2008). The share of Protestants is from Königliches Statistisches Landesamt (1824). The location of manufactories in 1832 is from Memminger (1833). Industrial employment 1829 is from various volumes of *Gewerbekataster* (Staatsarchiv Ludwigsburg E 258 VI). Elevation is from Bundesamt für Kartographie und Geodäsie (2017). The locations of rivers navigable in 1845 and paved roads in 1848 are from Kunz and Zipf (2008).

Table 2: Panel estimates of the effect of railway access on population

	Winners versus runners-up			Full sample		
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment effect	0.117***	0.136***	0.123***	0.172***	0.139***	0.143***
	(0.033)	(0.032)	(0.026)	(0.024)	(0.023)	(0.023)
Observations	3,276	3,276	3,276	38,766	38,766	38,766
Parish FE	Yes	Yes	Yes	Yes	Yes	Yes
Year × Case/County FE	No	Yes	Yes	No	Yes	Yes
Later access	No	No	Yes	No	No	Yes

Notes: The table shows panel regression estimates of the effect of railway access in 1845–54 on log population. Regressions (1) to (3) are estimated for the winners versus runners-up sample, regressions (4) to (6) for the complete sample excluding railway nodes. All regressions include a full set of year and parish dummies. Regressions (2) and (3) additionally include year-by-case fixed effects and regressions (5) and (6) include year-by-county (*Oberamt*) fixed effects. Regressions (3) and (6) add a time-varying control for railway access in later construction phases. Standard errors clustered at the parish level are in parentheses. ***, **, and * denote statistical significance at the 1, 5, and 10 percent level, respectively.

Sources: Population data are from Statistisches Landesamt Baden-Württemberg (2008).

Table 3: The effect of railway access on day laborer wages, taxable income, and building values

	Day laborer wage (*Pfennig*)						Taxable income (*Mark*)	Building value (*Mark*)	Fire insurance value (*Mark*)
	Female			Male					
	1884	1898	1909	1884	1898	1909	1907	1907	1908
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel A: IPW									
Treatment effect	7.013***	9.741***	8.171***	5.463**	9.669***	9.694**	48.305***	1,388.4***	1,749.0***
	(2.197)	(2.174)	(2.592)	(2.707)	(3.159)	(4.545)	(14.724)	(282.9)	(379.2)
Panel B: IPWRA									
Treatment effect	7.496***	9.962***	8.225***	5.714**	9.855***	9.679**	49.946***	1,388.2***	1,718.9***
	(2.381)	(2.268)	(2.542)	(2.829)	(3.146)	(4.521)	(14.204)	(283.5)	(385.9)
Panel C: OLS									
Treatment effect	8.055***	11.637***	9.831***	6.480**	11.939***	12.239***	57.598***	1,573.5***	1,881.0***
	(2.007)	(2.165)	(2.517)	(2.512)	(3.040)	(4.212)	(14.111)	(293.3)	(392.6)
Observations	155	156	156	156	156	156	156	156	156
Control mean	111.43	116.72	167.22	165.96	174.34	254.14	366.11	3,150.4	4,391.6

Notes: The table shows regression estimates of the effect of railway access in 1845–54 on the average daily wage of female (Columns (1) to (3)) and male (Columns (4) to (6)) day laborers in 1884, 1898, and 1909, on taxable income per capita in 1907 (Column (7)), the average value of buildings in 1907 (Column (8)), and the average fire insurance value per building in 1908 (Column (9)). Values in Columns (1) to (6) are in *Pfennig* and values in Columns (7) to (9) are in *Mark*, with 1 *Mark* = 100 *Pfennig*. Regressions in Panel A are estimated by IPW, regressions in Panel B by IPWRA and regressions in Panel C by OLS. All regressions include as control variables log population and log population density in 1834, the share of protestants in 1821, a dummy for having a manufactory in 1832, industry employment per 100 persons in 1829, elevation, dummies for access to a navigable river in 1845 and to a road in 1848, and case dummies. Robust standard errors are in parentheses. ***, **, and * denote statistical significance at the 1, 5, and 10 percent level, respectively.
Sources: The average daily wage of day laborers in 1884, 1898, and 1909, taxable income and building value in 1907, and the fire insurance value of buildings in 1908 are from Königliches Statistisches Landesamt (1898) and Königliches Statistisches Landesamt (1910).

Table 4: The effect of railway access on industrial development

	Employment				Establishment size (logs)	Steam engine	
	Industry		Agriculture			(0/1)	HP pc
	1895	1907	1895	1907	1895	1869	1869
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A: IPW							
Treatment effect	2.794**	2.789*	-3.741**	-6.740***	0.227**	0.206***	14.48**
	(1.426)	(1.465)	(1.513)	(2.037)	(0.094)	(0.065)	(5.719)
Panel B: IPWRA							
Treatment effect	2.889**	2.827**	-3.748***	-6.546***	0.228**	0.202***	14.52**
	(1.287)	(1.343)	(1.393)	(1.879)	(0.093)	(0.064)	(5.679)
Observations	156	156	156	156	156	156	156
Panel C: Panel estimates							
Treatment effect	3.149**	3.361**	–	–	0.221**	0.148*	14.71**
	(1.318)	(1.375)			(0.106)	(0.079)	(6.309)
Observations	312	312			311	312	312
Control mean	14.81	17.47	23.71	26.43	0.836	0.253	2.207

Notes: The table shows estimates of the effect of railway access in 1845–54 on the number of full-time employees in industry (Columns (1) and (2)) and agriculture (Columns (3) and (4)) per 100 persons in 1895 and 1907, establishment size in industry in 1895 (Column (5)), the probability of having installed at least one steam engine by 1869 (Column (6)), and steam horsepower per 1,000 persons in 1869 (Column (7)). Panels A and B display IPW and IPWRA estimates, respectively. Regressions in Panels A and B include as control variables log population and log population density in 1834, the share of protestants in 1821, a dummy for having a manufactory in 1832, elevation, dummies for access to a navigable river in 1845 and to a road in 1848, and case dummies. Panel C displays estimates from panel fixed effects regression that include parish and year-by-case fixed effects. The pre-treatment period is 1829 in Columns (1) to (5) and 1846 in Columns (6) and (7). We cannot run panel fixed effects regression for agricultural employment, as we lack data for the pre-treatment period. The control mean gives the mean value of the outcome for the control group in 1895 (Columns (1), (3), (5)) 1907 (Columns (2) and (4)) and 1869 (Columns (6) and (7)). Robust standard errors are in parentheses. Standard errors in Panel C are clustered at the parish level. ***, **, and * denote statistical significance at the 1, 5, and 10 percent level, respectively.

Sources: Employment data are from the occupation censuses of 1895 and 1907 (Königliches Statistisches Landesamt 1900a, 1910) and the *Gewerbestatistik* of 1829 (various volumes of *Gewerbekataster*, Staatsarchiv Ludwigsburg E 258 VI) and 1895 (Königliches Statistisches Landesamt 1900b). Data on the location of steam engines are from archival records (Staatsarchiv Ludwigsburg E 170 Bü 272).

Table 5: The effect of railway access on employment in key industrial sectors and specialization

	Employment in key industrial sectors					
		Coal, iron &	Machines & instruments		Chem-	Spec-
	Textile	steel	all	electrical	ical	ialization
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: IPW						
Treatment effect	2.491*	-0.051	0.530**	0.008	0.092	-0.020
	(1.333)	(0.107)	(0.240)	(0.009)	(0.091)	(0.018)
Panel B: IPWRA						
Treatment effect	2.549*	-0.071	0.527**	0.008	0.091	-0.018
	(1.308)	(0.128)	(0.239)	(0.009)	(0.091)	(0.018)
Observations	156	156	156	156	156	156
Panel C: Panel estimates						
Treatment effect	2.506*	-0.104	0.500*	0.008	0.082	-0.009
	(1.447)	(0.171)	(0.271)	(0.010)	(0.093)	(0.019)
Observations	312	312	312	312	312	311
Control mean	1.959	0.251	0.112	0.002	0.048	0.161

Notes: The table shows estimates of the effect of railway access in 1845–54 on the number of full-time employees per 100 persons in different industries (Columns (1)–(5)) and specialization within industry (Column (6)) in 1895. We distinguish between employment in the textile industry (Column (1)), coal, iron, and steel industry (Column (2)), building of machines and instruments (Column (3)), building of electrical machines and instruments (Column (4)), and the chemical industry (Column (5)). Specialization is measured by the Hirschman-Herfindahl-Index (with $\alpha = 2$). Panels A and B display IPW and IPWRA estimates, respectively, using employment in 1895 as outcome variable. Regressions in Panels A and B include as control variables log population and log population density in 1834, industry employment per 100 persons in 1829, a dummy for having a manufactory in 1832, the share of protestants in 1821, elevation, dummies for access to a navigable river in 1845 and to a road in 1848, and case dummies. Panel C displays estimates from panel fixed effects regression that include parish and year-by-case fixed effects. The pre-treatment period is 1829. The control mean gives the mean value of the outcome for the control group in 1895. Standard errors in Panel C are clustered at the parish level. ***, **, and * denote statistical significance at the 1, 5, and 10 percent level, respectively.

Sources: Employment data are from the *Gewerbestatistik* of 1829 (various volumes of *Gewerbekataster*, Staatsarchiv Ludwigsburg E 258 VI) and 1895 (Königliches Statistisches Landesamt 1900b).

Table 6: Heterogeneous effects of railway access on population, DiD estimates

	(1)	(2)	(3)
Linear time break	0.006***	0.005***	0.004***
	(0.001)	(0.001)	(0.001)
Linear time break ×			
Manufactory 1832		0.007***	
		(0.002)	
Population 1843 > Treatment group median			0.005***
			(0.002)

Notes: The table shows panel regression estimates of the effect of railway access in 1845–54 on log population, based on the full sample excluding railway nodes (38,766 observations). We assume that the treatment effect is a linear time break. Thus, we interact $Line_{ijt}$ in equation (1) with the difference between year t and the year a line was opened (plus one). All regressions include a full set of parish dummies and year-by-county fixed effects. Regressions (2)–(3) add interaction terms between the treatment (linear time break) and pre-railway parish characteristics, namely the existence of a manufactory in 1832 (regression (2)) and above-median population in 1843 (regression (3)). Standard errors clustered at the parish level are in parentheses. ***, **, and * denote statistical significance at the 1, 5, and 10 percent level, respectively.
Sources: Population data are from Statistisches Landesamt Baden-Württemberg (2008).

Table 7: Heterogeneous effects of railway access on day laborer wages, taxable income, building values, and industrial development

	Day laborer wage (*Pfennig*)		Taxable income (*Mark*)	Building value (*Mark*)	Fire insurance value (*Mark*)	Industry employment	Establishment size (logs)	Steam engine	
	Female	Male						(0/1)	HP pc
	1909	1909	1907	1907	1908	1907	1895	1869	1869
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel A: Average effects									
Treatment dummy	9.850***	16.087***	61.462***	1,226.9***	1,497.0***	6.738***	0.460***	0.215***	6.230**
	(2.154)	(3.670)	(12.474)	(250.2)	(313.1)	(0.834)	(0.083)	(0.062)	(2.930)
Panel B: Heterogeneity by manufactory 1832									
Treatment dummy	8.411***	13.913***	55.835***	1,106.8***	1,291.0***	6.251***	0.396***	0.160***	4.418
	(2.119)	(3.728)	(12.628)	(249.5)	(307.0)	(0.821)	(0.081)	(0.061)	(2.892)
Treatment dummy ×	17.748**	26.797**	69.362	1,480.3	2,539.4*	6.327**	0.836***	0.791***	26.074***
Manufactory 1832	(8.504)	(11.549)	(50.952)	(1,132.3)	(1,322.8)	(3.120)	(0.305)	(0.071)	(10.389)
Panel C: Heterogeneity by population 1843									
Treatment dummy	5.702*	11.727**	32.766**	795.1***	1,210.9***	5.103***	0.244**	0.152**	5.527*
	(2.965)	(5.186)	(13.154)	(159.3)	(332.8)	(1.116)	(0.109)	(0.077)	(2.852)
Treatment dummy ×	8.470**	8.902	58.591**	881.6*	584.1	3.339**	0.440***	0.137	1.523
Above-median population 1843	(4.077)	(7.062)	(23.489)	(480.1)	(599.5)	(1.560)	(0.162)	(0.128)	(6.260)
Observations	1,843	1,843	1,843	1,843	1,843	3,686	3,318	3,692	3,692
Control mean	165.76	246.96	320.96	2,763.9	3,794.0	11.058	0.478	0.073	1.002

Notes: The table shows heterogeneity in the effect of railway access in 1845–54 on the average daily wage of female (Column (1)) and male (Column (2)) day laborers in 1909, on taxable income per capita in 1907 (Column (3)), the average value of buildings in 1907 (Column (4)), the average fire insurance value per building in 1908 (Column (5)), the number of full-time employees in industry per 100 persons in 1907 (Column (6)), establishment size in industry in 1895 (Column (7)), the probability of having installed at least one steam engine by 1869 (Column (8)), and steam horsepower per 1,000 persons in 1869 (Column (9)). Estimates in Columns (1) to (5) are from cross-sectional OLS regressions on the full sample. Control variables include log population and log population density in 1834, the share of protestants in 1821, a dummy for having a manufactory in 1832, industry employment per 100 persons in 1829, elevation, dummies for access to a navigable river in 1845 and to a road in 1848, a dummy indicating whether population in the main location of residence in 1843 was above the treatment group median, and dummies for geographic location within Württemberg. Estimates in Columns (6) to (9) are from panel fixed effects regressions that include parish and year-by-county fixed effects. Regressions in Panel (A) report average effects of railway access. Regressions in Panels (B) and (C) add interaction terms between the treatment effect dummy and (pre-railway or time-invariant) parish characteristics, namely the existence of a manufactory in 1832 (Panel (B)) and above-median treatment group population in 1843 (Panel (C)). Robust standard errors, clustered at the parish level in Columns (6) to (9), are in parentheses. ***, **, and * denote statistical significance at the 1, 5, and 10 percent level, respectively.

Sources: See the notes to Tables 3 and 4.

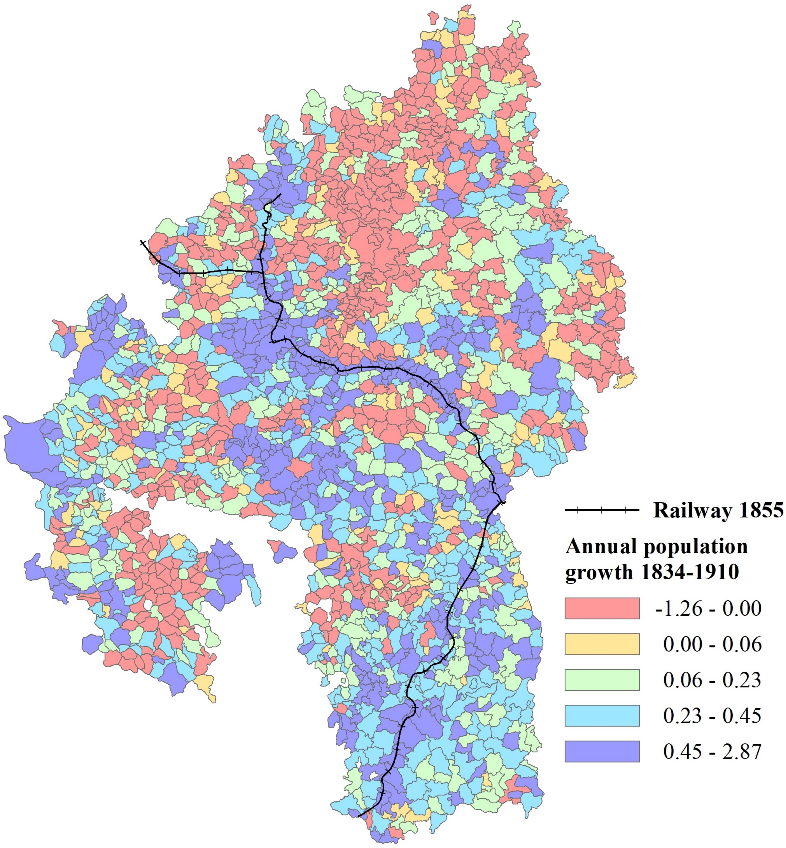

Figure 1: Average annual population growth in 1834–1910

Notes: The figure shows the average annual population growth in parishes in Württemberg between 1834 and 1910. The solid black line depicts the railway network in 1855.
Sources: Kunz and Zipf (2008), Dumjahn (1984), Kommission für geschichtliche Landeskunde in Baden-Württemberg and Landesvermessungsamt Baden-Württemberg (1972), Statistisches Landesamt Baden-Württemberg (2008). Authors' design.

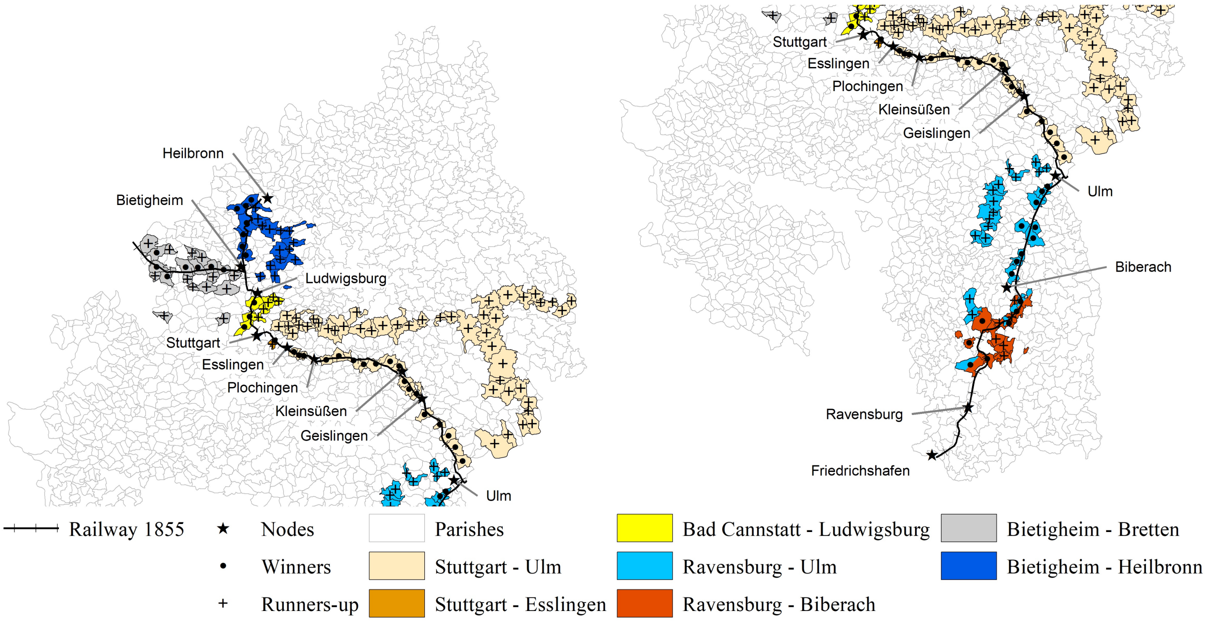

Figure 2: Winner and runner-up parishes

Notes: The figure shows railway nodes (stars), 'winner parishes' (points) and 'runner-up parishes' (crosses). The nodes are labeled in the map. Winners are parishes that obtained railway access in the first construction stage (but are not nodes). Runners-up are parishes with designated railway access on an alternative line that was eventually not built in the first stage of the railway expansion. Colors distinguish between the different cases and mark all potential routes suggested for one railway line. 'Gaps' between winners or runners-up along a proposed route arise because not all parishes traversed by a railway line were (meant to be) connected to the railway.

Sources: Dumjahn (1984), Etzel et al. (1985), Kunz and Zipf (2008), Kommission für geschichtliche Landeskunde in Baden-Württemberg and Landesvermessungsamt Baden-Württemberg (1972), and Königliches Statistisches Landesamt (1911). Authors' design.

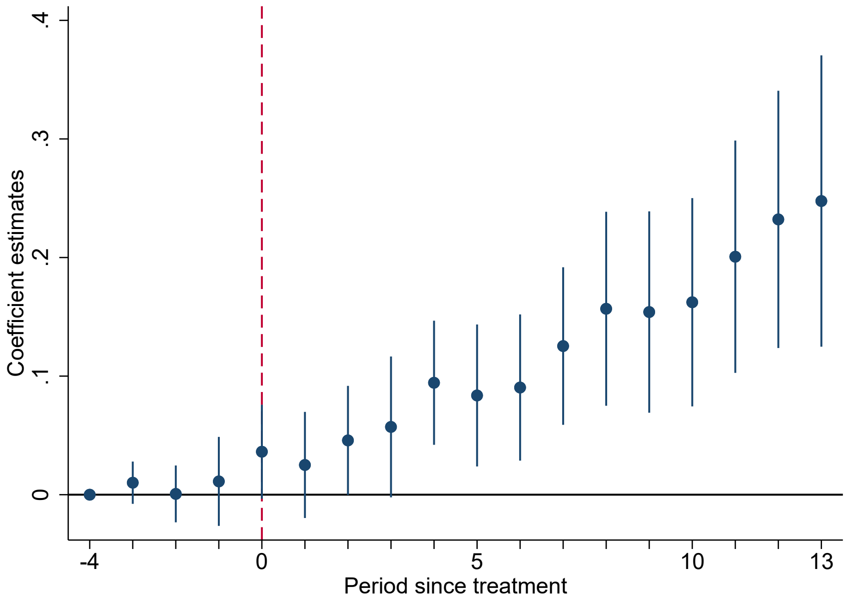

Figure 3: Event study estimates of the effect of railway access on log population

Notes: The graph depicts differences in log population between winner and runner-up parishes for pre- and post-treatment periods, as estimated in an event study regression. Differences are expressed relative to the baseline difference four periods before the treatment. Point estimates are marked by a dot. The vertical bands indicate the 95 percent confidence interval of each estimate. The red dashed vertical line indicates the treatment period.

Sources: Population data are from Statistisches Landesamt Baden-Württemberg (2008).

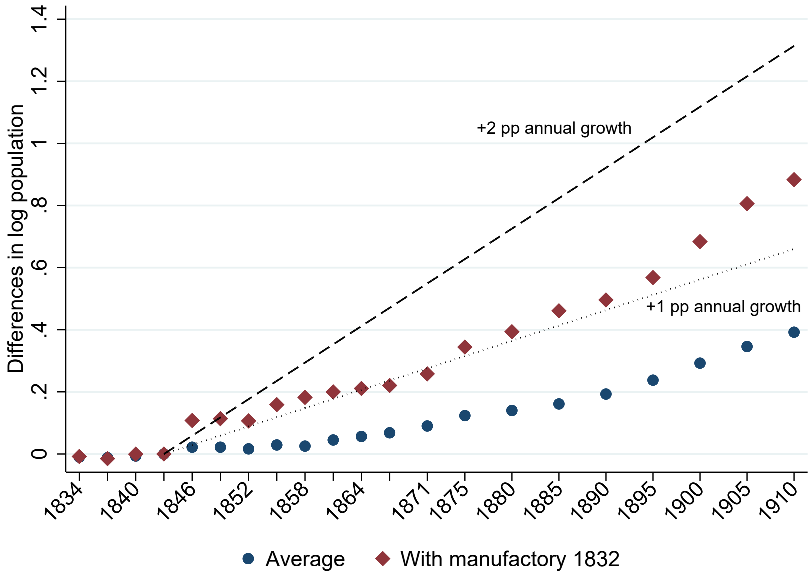

Figure 4: Differences in log population between railway and non-railway parishes, 1834–1910

Notes: The graph depicts differences in log population between railway and non-railway parishes in 1834–1910, as estimated in panel regressions with parish and year-by-county fixed effects. Blue dots mark the average growth estimate, red diamonds those estimated for railway parish that had a manufactory in 1832. Estimates are based on the full sample, excluding railway nodes. 1843 serves as the baseline period. The black dotted and dashed lines show how differences in log population would have evolved if railway access had increased annual population growth by 1 and 2 percentage points, respectively.
Sources: Population data are from Statistisches Landesamt Baden-Württemberg (2008).

Online Appendix

Appendix 1 Württemberg in the German Empire

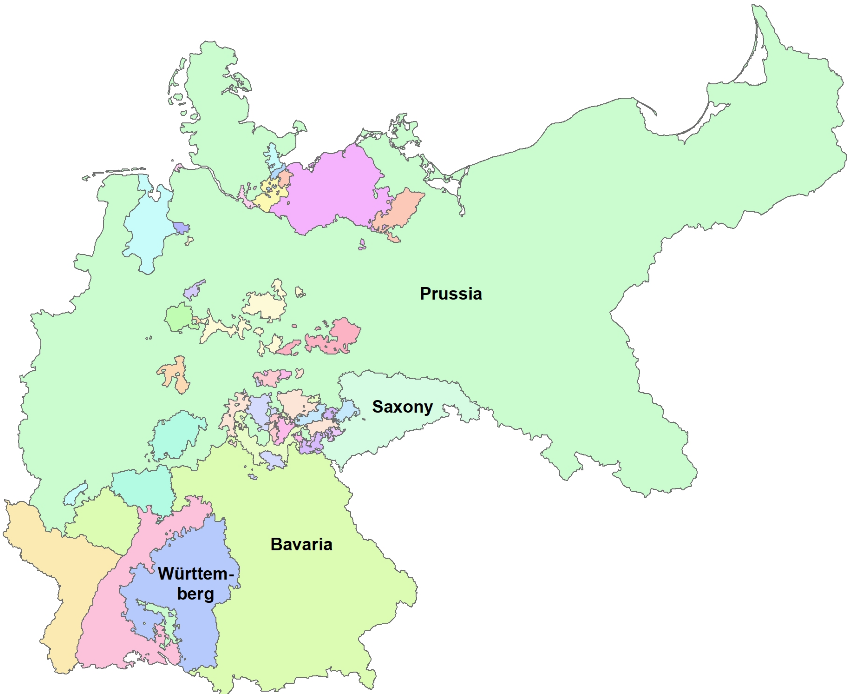

Figure A-1: The German Empire in 1871

Notes: The figure shows the German Empire in its 1871 borders. Labels mark the four Kingdoms that were part of the German Empire (namely, the Kingdoms of Bavaria, Prussia, Saxony and Württemberg).
Source: Max Planck Institute for Demographic Research (MPIDR) and Chair for Geodesy and Geoinformatics, University of Rostock (CGG) (2011). Authors' design.

Appendix 2 Network development stages in the Kingdom of Württemberg 1845–1910

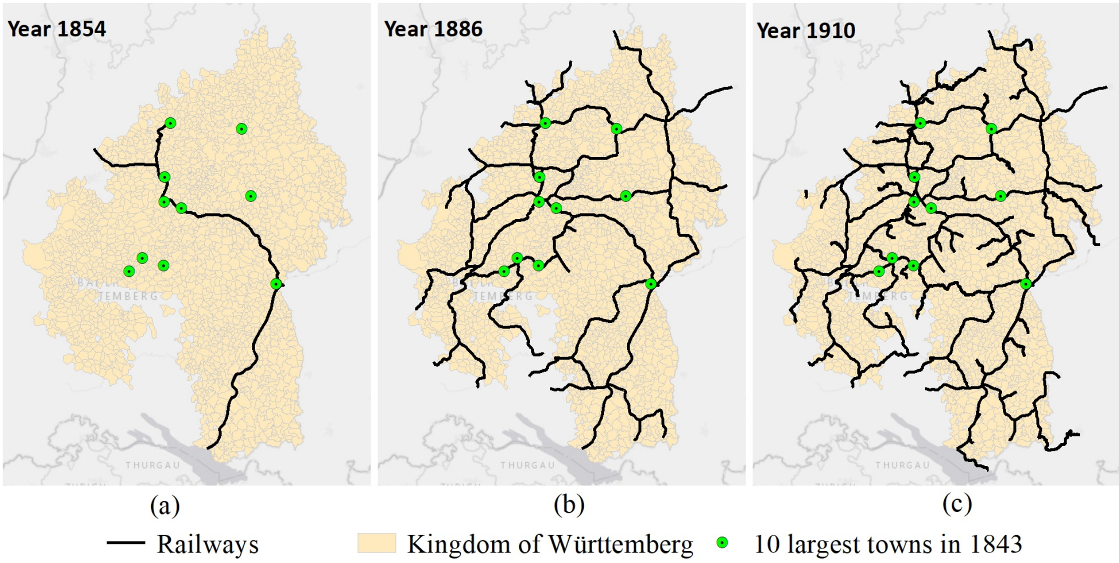

Figure A-2: Network development stages in the Kingdom of Württemberg 1845–1910

Notes: Panels (a), (b), and (c) show the railway network at the end of the construction phases in 1854, 1886, and 1910, respectively.

Sources: Kunz and Zipf (2008), Dumjahn (1984), Kommission für geschichtliche Landeskunde in Baden-Württemberg and Landesvermessungsamt Baden-Württemberg (1972), and Esri HERE Delorme, MapmyIndia, OpenStreetMap© contributors, and the GIS map user community. Authors' design.

Appendix 3 Regional economic development in Württemberg

Table A-1: Development indicators of Württemberg's districts

	National income per capita (in % of average)		Agricultural employment share (in %)	Urbanization rate (in %)
	1849	1907/13	1907	1910
Neckarkreis	111.2	113.3	30.0	53.9
Schwarzwaldkreis	96.8	85.5	44.8	32.4
Jagstkreis	88.0	72.6	52.9	23.1
Donaukreis	96.6	85.7	45.3	32.6
Württemberg			41.3	38.7
German Empire	100	100	32.7	44.3

Notes: The urbanization rate measures the percent of the total population living in urban municipalities of 2,000 or more inhabitants.

Source: Data on national income per capita is taken from Frank (1993), data on agricultural employment is from Kaiserliches Statistisches Amt (1910, 1913), and data on urbanization from Kaiserliches Statistisches Amt (1915).

Appendix 4 The planning process for the central line

This section outlines the planning process for the central line (*Zentralbahn*), the first railway line constructed in Württemberg. The central line was destined to connect the capital Stuttgart with Ludwigsburg in the north and with Cannstatt and Esslingen in the east.

On behalf of the government, building officer Georg von Bühler and engineer Carl von Seeger worked out the first detailed plan of the central line in 1836–39 (Mühl and Seidel 1980). Figure A-3 sketches their proposed route (thin red dashed line), along with three later proposals that we discuss below. Von Bühler and von Seeger's route mostly follows the river Neckar. Beginning in Ludwigsburg, the route heads east and then follows the western shore of the river. The route from Cannstatt to Stuttgart branches of the main line. By following the flat shore of the river, von Bühler and von Seeger's proposal reduced height differences and kept the railway gradient below a threshold of 1:100 (Etzel et al. 1985). The expected construction costs for the central line amounted to 3,390,430 *Gulden* (von Reden 1846).

In 1839, Württemberg's parliament asked for another expert to inspect the existing railway plans. Alois Negrelli, a chief engineer at the Emperor Ferdinand Northern Railway in Vienna (*Kaiser Ferdinands-Nordbahn*), approved the plans of von Bühler and von Seeger in 1843 and recommended only minor changes (Mühl and Seidel 1980). His proposal is delineated by the thin red dash-dotted line in Figure A-3.

After Negrelli's report, the parliament was largely convinced of the feasibility of a railway network and asked the government to appoint a railway commission to elaborate on the technical aspects. The commission entrusted engineers Charles Vignoles (eponym of the Vignoles rail), Ludwig Klein, Karl Etzel, and Michael Knoll with examining various railway lines (Mühl and Seidel 1980).

Figure A-3 illustrates the routes proposed for the central line by Vignoles in 1843 (bold

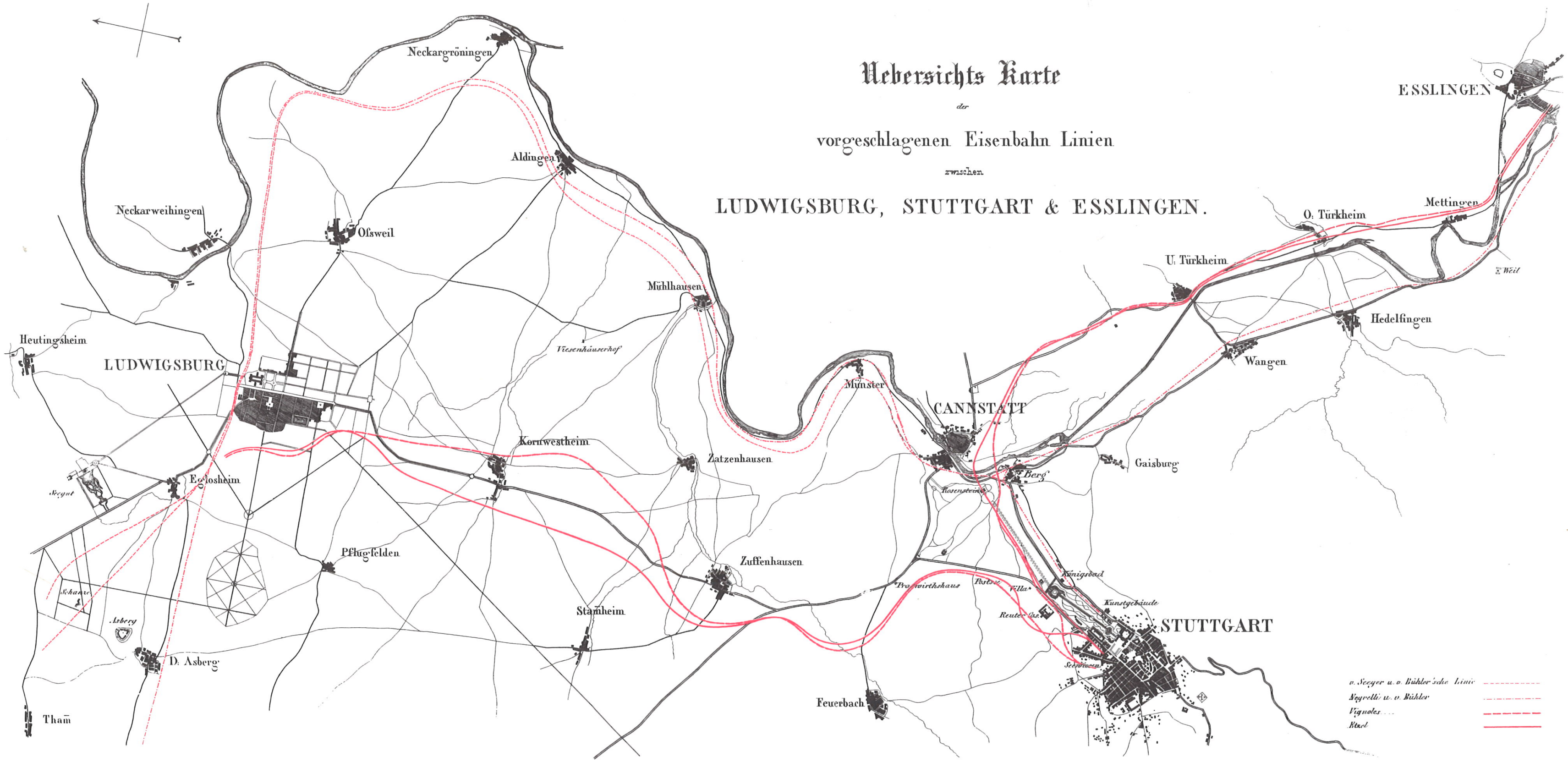

Figure A-3: Route proposals for the central line (*Zentralbahn*) in 1844

Notes: The figure shows the four different routes of the central line proposed during the planning process by von Bühler and von Seeger in 1839 (thin red dashed line), Negrelli in 1843 (thin red dashed-dotted line), Vignoles in 1843 (bold red dashed line), and Etzel in 1844 (bold red solid line).
Source: Etzel et al. (1985).

red dashed line) and Etzel in 1844 (bold red solid line). Both proposals significantly changed the initial plans by recommending two separate lines that both start in Stuttgart. The first line connects Stuttgart to Ludwigsburg on a shorter route, which does not follow the Neckar but requires a tunnel near Feuerbach. The second line crosses the Neckar near Cannstatt and then follows the eastern shore of the river to Esslingen. The additional tunnel (and inflation) increased the estimated construction costs for Etzel's proposal to 3,732,380 *Gulden* (von Reden 1846).

The railway commission finally asked engineer Ludwig Klein to re-evaluate all existing proposals. Klein argued in his report that expected traffic–and thus the catchment area of a line–determines the turnover of a railway but that costs–and thus technical aspects of the line–drive profits (Etzel et al. 1985). Consequently, Klein's report compares the proposals mainly under technical aspects.

In particular, Klein compared proposals I. by von Bühler and von Seeger (including Negrelli's refinement), II. by Vignoles, and III. by Etzel based on their overall length, curvature, height difference, gradient, and weighted length (which accounts for curvature and gradient). Panel A of Table A-2 shows the results of this comparison for the line between Stuttgart and Esslingen. Route I. has the shortest length, both unweighted (44,600 feet) and weighted (49,100 feet). However, it also has the highest maximum gradient (1:100) and the lowest minimum curve radius (800 feet). Klein thus recommended route III., which dominates route II. in all aspects (Etzel et al. 1985).

Panel B of Table A-2 shows the corresponding values for the three alternative routes of the line Stuttgart-Ludwigsburg. Again, Klein recommended route III. to the government. Route III. is the shortest of all three alternatives, both in terms of unweighted and weighted length. It also has the largest minimum curve radius and the lowest maximum gradient. The government followed Klein's recommendations and choose proposal III. for both lines. Construction works

Table A-2: Comparison of alternatives for the central line by Klein in 1844

Route	Length	Length of		Smallest	Height	Maximum	Weighted
		Straight lines	Curves	curve radius	difference	gradient	length
	(feet)	(feet)	(feet)	(feet)	(feet)		(feet)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: Stuttgart to Esslingen							
I.	44,600	33,100	11,500	800	119.3	1:100	49,100
II.	50,200	26,000	24,200	1,000	161.0	1:115	60,960
III.	49,260	30,875	18,385	1,200	144.0	1:125	56,600
Panel B: Stuttgart to Ludwigsburg							
I.	79,000	46,690	32,310	800	273.2	1:100	96,865
II.	54,105	26,085	28,020	1,500	228.7	1:125	64,619
III.	51,988	22,840	29,148	1,600	234.3	1:125	63,261

Notes: The table compares different routes for the line from Stuttgart to Esslingen (Panel A) and Stuttgart to Ludwigsburg (Panel B) proposed by von Bühler and von Seeger (I.), Vignoles (II.), and Etzel (III.) based on the length in total (Column(2)), of straight lines (Column (3)) and of curves (Column(4)). The table also shows the smallest curve radius (Column (5)), the height difference (Column (6)), the maximum gradient (Column (7)), and the weighted length (Column (8)), in other words, total length plus a penalty for curves and gradient. Distances in Württemberg feet, with 1,000 feet = 286.49 meters.

Source: Based on Tables XVI and XVIII from the report of Klein (1844) (Etzel et al. 1985, pages 71 and 76).

began in June 1844. The first segment between Stuttgart and Esslingen was finished in November 1845, and the central line was completed in October 1846.

Our empirical analysis defines Obertürkheim as winning parish on the line Stuttgart-Esslingen and Feuerbach, Kornwestheim, Zuffenhausen as winning parishes on the line Stuttgart-Ludwigsburg. These parishes were only connected to the railway because the eventually built route followed Etzel's proposal and not von Bühler and von Seeger's earlier plans. Losing parishes are those that would have been connected to the railway under Bühler and von Seeger's plans but not under Etzel's (see Table A-4 for a list of winning and losing parishes by railway line).

Appendix 5 Density of Württemberg's railway network in comparison

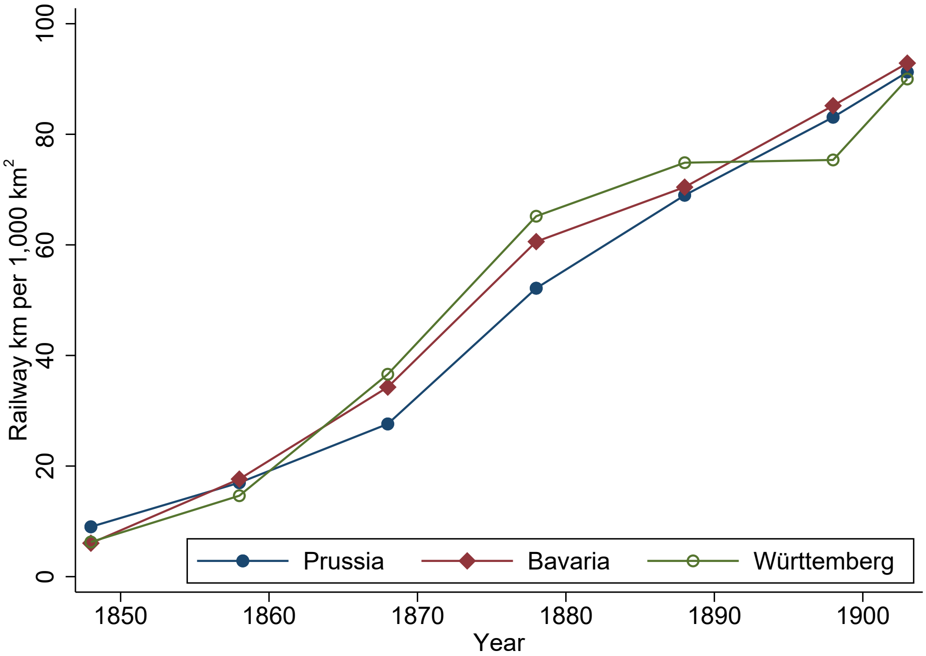

Figure A-4: Density of railway network in Bavaria, Prussia, and Württemberg, 1848–1903

Notes: The figure shows the density of the railway network in Bavaria, Prussia, and Württemberg from 1848 to 1903. Density is measured as the total length of the railway network (in km) over the land area of a state (in 1000 km^2).

Sources: The length of the railway network is from Lenschau (1906) and area is from Kaiserliches Statistisches Amt (1903). Authors' design.

Appendix 6 Annual revenue and transport statistics of Württemberg's public railway

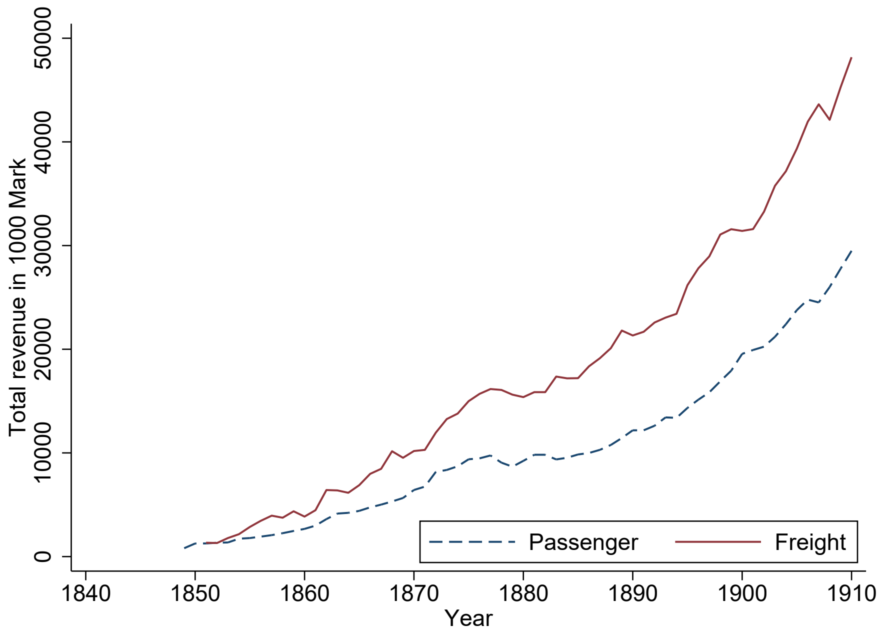

Figure A-5: Annual revenue of the public railway by passengers and freight, 1853–1910

Notes: The figure shows the total revenue of the public railway company in Württemberg 1853–1910 by passengers and freight in 1,000 *Mark*.

Source: Fremdling, Federspiel, and Kunz (1995). Authors' design.

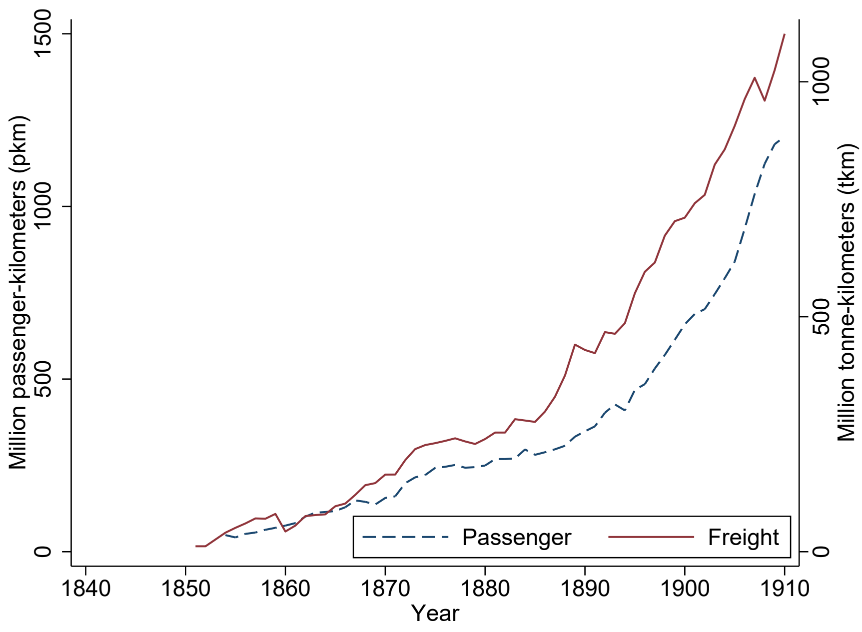

Figure A-6: Annual transport statistics of the public railway by passengers and freight, 1853–1910

Notes: The figure shows annual transport statistics of the public railway company in Württemberg 1853–1910 for passengers and goods. The dashed line shows million passenger-kilometers and the solid line million tonne-kilometers.

Source: Fremdling, Federspiel, and Kunz (1995). Authors' design.

Appendix 7 Political representation, lobbying, and railway access

By contemporary standards, Württemberg's parliament exercised unusually strong control over the executive. Manned by business interest, it supported and maintained the power of local communities, guilds, and cartels (Ogilvie, Küpker, and Maegraith 2009; Ogilvie and Carus 2014). We might thus expect that lobbying and political pressure had profound effects also on the routing of the railway. If so, winning and losing parishes might systematically differ, insofar as the former were more successful in their lobbying efforts. This might also explain why winners tended to be smaller and less industrialized than runners-up (see Table 1). As less dynamic places, they might have been better for political connections.

It is beyond the scope of this paper to comprehensively assess the influence that local special interest group–through lobbying and political pressure–had on the routing of the railway. We nevertheless think that any such influence was presumably small, at least in the first stage of the railway expansion. There are several reasons for this assessment.

First, the decision as to where to build rested primarily with the government, not the parliament (Mann 2006). This was because local communities naturally had conflicting interests, which made decision-making in the parliament difficult. Parliamentary representatives did not agree on whether to build a railway in the first place (Mühl and Seidel 1980; Supper 1895). Some argued that Württemberg, as an agrarian country, did not need a railway. Others pointed to the disastrous consequences of the railway for carters and other trades, and to the burden imposed by state railways on taxpayers in remote areas without railway access. After long-lasting debates, the majority nevertheless agreed to the railway bill of 1843, which legislated the first stage of Württemberg's railway expansion (see the "Background" section for details).

Naturally, conflicts also arose over the exact routes of the lines, stated in the railway bill. A key debate in the first construction phase was over the route of the *Ostbahn* from Cannstatt to Ulm. The first, and eventually realized, route ran via Göppingen through the Fills Valley (so-called *Filstalbahn*). The alternative route ran via Aalen through the valleys of Neckar, Rems and Brenz (so-called *Remsbahn*). While the Remsbahn bypassed the Swabian Alb, it was considerably longer than the *Filsbahn* and ran partly over Bavarian territory (Figure 2 in the main text maps the proposed alternatives). Therefore, Alois Negrelli, the first external expert commissioned to inspect Württemberg's railway plans, strongly advocated the *Filstalbahn.* His strong rejection of the *Remsbahn* prompted local interest groups to commission a counter assessment, which, however, was eventually refuted by the second external expert, Ludwig Klein.

Second, the important role played by external experts arguably limited the influence of local special interest groups (see, for example, Mühl and Seidel 1980; von Morlok 1890; Supper 1895, for detailed descriptions of the reports written by these experts and their influence on the decision process). Importantly, Alois Negrelli and Ludwig Klein both came from outside Württemberg. Negrelli oversaw the construction of railways in the Austrian Empire and Switzerland, and also advised the Kingdom of Saxony. Klein came from Vienna to Württemberg, and had previously worked in Russia and the US. His influential report of 1843, approved by the railway commission and the ministry, explicitly states that "circumstances of local nature" must not be considered in his scientific evaluation of existing proposals (von Morlok 1890, p. 24). Instead, Klein argues that the expected traffic and costs of a line should be the only two decision criteria. His report is also explicitly written on the premise that no economic or political obstacles stand in the way of any of the proposed lines.

Third, the railway bill of 1843 limited the scope of towns to lobby for a railway access in the first construction phase, as it determined both the general direction and destination of Württemberg's main lines.[1] An exception was the western line, for which the bill did not specify a destination due to the pending negotiations with Baden. However, the route of the western

[1]In contrast, Mühl and Seidel (1980) discuss a number of examples where towns tried to influence the direction of railway lines in the second and third expansion stage.

line was mainly determined in direct negotiations between Baden and Württemberg.[2]

Fourth, we find no empirical evidence that parishes with direct connections to representatives in either the parliament or the advisory privy council (*Geheimer Rat*) were more likely to gain access to the railway in the first construction phase.[3] We construct two measures for political connections. The first indicates whether at least one representative of the nobility in the privy council or parliamentary estates owned land in a parish. The second indicates whether at least one of the elected representatives of the parliament had his place of work in a parish. Information on the names of representatives and their workplaces as well as the landholdings of the nobility refer to 1843 and come from Königliches Statistisches Landesamt (1843).

Table A-3 report OLS regression estimates of the effect of political connections on the probability of gaining railway access in 1845–54, both for the winners versus runners-up sample

[2]While Württemberg had approached Baden already in 1838 for negotiations about the connection of their networks, Baden initially focused on the connection of its railway with Switzerland (in an attempt to exclude Württemberg from this trade route). However, Württemberg finished its main line, and thus the connection to Lake Constance and Switzerland, already in June 1850, and thus earlier than Baden. Only then was Baden interested in connecting its network to Württemberg's, also to redirect trade flows between the Netherlands and Austria-Hungary from more northern trade routes. Württemberg preferred a connection in the north between Heidelberg and Heilbronn, while Baden preferred a line between Durlach and Bietigheim in the south. Both countries favored the connection that kept the trains as long on their territories as possible. On December 4, 1850, they agreed to connect both networks between Bruchsal in Baden and Bietigheim in Württemberg, which is in the middle of their initial proposals.

[3]The constitution of September 1819 turned Württemberg into Germany's first constitutional monarchy. The legislature was organized into two chambers. Members of the first chamber (*Ständekammer*) were the princes of the House of Württemberg, representatives of the nobility, and nominees of the King. Member of the second chamber (*Abgeordnetenkammer*) were 70 elected representatives of the administrative districts (Oberämter) and largest towns as well as 23 'privileged representatives' (namely, representatives of the knightly nobility, the churches, and the chancellor of the University of Tübingen). The re-established privy council acted as a link between the parliamentary estates and the King. As the highest state bureaucracy, the council was directly subordinate to the King. It consisted of the ministers and additional members appointed by the King.

Table A-3: OLS estimates of the effect of political connections on railway access

	Dependent variable: Railway access 1845–1854 (0/1)			
	(1)	(2)	(3)	(4)
Panel A: Winners vs. runners-up				
Noble landholder (0/1)	0.062	0.021		
	(0.084)	(0.093)		
Place of work (0/1)			-0.152	-0.086
			(0.145)	(0.135)
Control variables	No	Yes	No	Yes
Observations	156	156	156	156
Panel B: Full sample				
Noble landholder (0/1)	-0.004	-0.006		
	(0.009)	(0.009)		
Place of work (0/1)			0.017	-0.021
			(0.035)	(0.040)
Control variables	No	Yes	No	Yes
Observations	1,846	1,846	1,846	1,846

Notes: The table shows OLS regression estimates of the effect of political connections on the probability of gaining railway access in 1845–54. Regressions in Panel A are estimated for the winners versus runners-up sample, regressions in Panel B for the complete sample excluding railway nodes. Regressions in Columns (1) and (2) measure political connections with a dummy indicating whether at least one representative of the nobility in the privy council or parliamentary estates owned land in a parish. Regressions in Columns (3) and (4) measure political connections with a dummy indicating whether at least one of the elected representatives of the parliament had his place of work in a parish. Regressions in Columns (2) and (4) include as control variables log population and log population density in 1834, the share of protestants in 1821, a dummy for having a manufactory in 1832, industry employment per 100 persons in 1829, elevation, dummies for access to a navigable river in 1845 and to a road in 1848, and case dummies. Robust standard errors are in parentheses. ***, **, and * denote statistical significance at the 1, 5, and 10 percent level, respectively.
Sources: The names of representatives and their workplaces as well as the landholdings of the nobility are from Königliches Statistisches Landesamt (1843).

(Panel A) and the full sample (Panel B). Columns (1) and (3) show unconditional estimates, whereas Columns (2) and (4) condition on our usual control variables. None of the specifications indicates a statistically significant effect of political connections on railway access. Of course, our measures of political connections are at best imperfect proxies. The empirical results in Table A-3 should thus not be taken as definite evidence against the importance of lobbying and political pressure for the routing of the railway. Nevertheless, they are consistent with our general assessment that any such influence was presumably small.

Appendix 8 List of winning and losing parishes

Table A-4 shows the list of winning and losing parishes by case and railway line. We exclude railway nodes and parishes that would have been connected to the railway under all alternative proposals from the list.

Table A-4: Winning and losing parishes by case

Case	Line	Winning parishes	Losing parishes
(1)	(2)	(3)	(4)
1	Stuttgart - Ulm	Altbach, Altenstadt, Amstetten, Beimerstetten, Ebersbach an der Fils, Faurndau, Gingen an der Fils, Göppingen, Großeislingen, Jungingen, Kuchen, Lonsee, Oberesslingen, Obertürkheim, Reichenbach an der Fils, Salach, Uhingen, Westerstetten, Zell am Neckar	Aalen, Aufhausen, Beinstein, Bergenweiler, Beutelsbach, Bolheim, Bopfingen, Endersbach, Essingen, Fellbach, Geradstetten, Giengen an der Brenz, Großdeinbach, Grunbach, Heidenheim a.d. Brenz, Herbrechtingen, Herlikofen, Hermaringen, Königsbronn, Langenau, Lauchheim, Lorch, Mergelstetten, Mögglingen, Niederstotzingen, Oberkochen, Oberurbach, Pflaumloch, Plüderhausen, Rammingen, Rommelshausen, Röttingen, Schorndorf, Schwäbisch Gmünd, Sontheim an der Brenz, Stetten im Remstal, Trochtelfingen, Unterböbingen, Unterkochen, Waiblingen, Waldhausen, Wasseralfingen, Weiler (Rems), Westhausen, Winterbach

Continued on next page

Table A-4 – *Continued from previous page*

Case	Line	Winning parishes	Losing parishes
(1)	(2)	(3)	(4)
2	Stuttgart - Esslingen	Obertürkheim	Hedelfingen
3	Bad Cannstatt - Ludwigsburg	Feuerbach, Kornwestheim, Zuffenhausen	Aldingen am Neckar, Mühlhausen, Münster, Neckargröningen, Neckarrems
4	Biberach - Ulm	Achstetten, Einsingen, Erbach, Grimmelfingen, Langenschemmern, Laupheim, Rißtissen, Schemmerberg, Schweinhausen, Ummendorf, Unteressendorf, Warthausen, Wolpertswende	Allmendingen, Bad Buchau, Berkach, Blaubeuren, Dettingen, Ehingen (Donau), Ehrenstein, Gerhausen, Herrlingen, Klingenstein, Munderkingen, Reichenbach bei Schussenried, Rottenacker, Schelklingen, Schmiechen
5	Ravensburg - Biberach	Aulendorf, Bad Schussenried, Reute, Schweinhausen, Ummendorf, Unteressendorf, Wolpertswende	Bad Waldsee, Hochdorf, Michelwinnaden, Rißegg, Steinach, Winterstettenstadt

Continued on next page

Table A-4 – *Continued from previous page*

Case	Line	Winning parishes	Losing parishes
(1)	(2)	(3)	(4)
6	Bietigheim - Bretten	Dürrmenz/Mühlacker, Ensingen, Großsachsenheim, Illingen, Maulbronn, Ötisheim, Sersheim	Aurich, Bissingen an der Enz, Ditzingen, Enzberg, Enzweihingen, Friolzheim, Gündelbach, Horrheim, Knittlingen, Markgröningen, Oberriexingen, Roßwag, Zaisersweiher
7	Bietigheim - Heilbronn	Besigheim, Böckingen, Kirchheim am Neckar, Klingenberg, Lauffen am Neckar, Nordheim, Walheim	Auenstein, Beihingen am Neckar, Beilstein, Großbottwar, Hof und Lembach, Ilsfeld, Kleinbottwar, Marbach am Neckar, Murr, Oberstenfeld, Schozach, Sontheim, Steinheim an der Murr, Talheim

Appendix 9 Semi-parametric models

This section provides technical details on IPW and IPWRA models (see Imbens and Wooldridge (2009) and Wooldridge (2010) for a thorough discussion), which we estimate using Stata's 16.1 command `teffects`.

Average treatment effect on the treated (ATT). The parameter γ in models (1) and (2) can be interpreted as the ATT, provided that the linearity assumption inherent in these models holds. Let $y^{\tau}_{ijt}(d)$ denote the potential outcome at time $t+\tau$ of parish i of case j whose winning line was opened in t. Here, $d \in \{0,1\}$ indicates railway access, so that $y^{\tau}_{ijt}(1)$ denotes the potential outcome with railway access and $y^{\tau}_{ijt}(0)$ the potential outcome without railway access. We furthermore define the potential outcome growth between periods $t-4$ and $t+\tau$ as $\Delta y^{\tau}_{ijt}(d) = y^{\tau}_{ijt}(d) - y_{ijt-4}$. The causal effect of railway access at time t on the outcome of interest after τ periods is

$$\gamma_{att,\tau} \equiv \mathbb{E}\left[\Delta y^{\tau}_{ijt}(1) - \Delta y^{\tau}_{ijt}(0) \mid D_{ij,1855} = 1\right]. \tag{A-1}$$

As in the event study analysis, we again express population relative to a baseline four periods before the treatment. Assumption 2 then applies to the difference rather than the level in potential outcomes, i.e., $(\Delta y^{\tau}_{ijt}(1), \Delta y^{\tau}_{ijt}(0)) \perp D_{ij,1855} \mid \boldsymbol{X}_i$.

Inverse probability weighting. IPW estimates the ATT by comparing *weighted* outcome means of parishes with and without railway access, placing more weight on observations in the control group that–given their covariates–had a high probability of being treated in the first place. More specifically, IPW first uses a probit model to estimate the propensity score–or probability–of being in the treatment group (in other words, of $D_{ij,1855} = 1$) conditional on covariates $\boldsymbol{X}_i$. We then use the predicted propensity score $\hat{P}_i$ to re-weight the outcome variable, applying the efficient weights $\hat{w}_i$ of Hirano, Imbens, and Ridder (2003):

$$\hat{w}_i = \begin{cases} 1/\hat{\mathbb{E}}\left[D_{ij,1855}\right] \text{ if } D_{ij,1855} = 1, \\ -\hat{P}_i / \left[\hat{\mathbb{E}}[D_{ij,1855}](1-\hat{P}_i)\right] \text{ if } D_{ij,1855} = 0, \end{cases} \tag{A-2}$$

where $\hat{\mathbb{E}}[X \mid S]$ denotes the sample average of X for all observations in a set S. $\hat{\mathbb{E}}[D_{ij,1855}]$ in equation (A-2), for instance, is simply the fraction of parishes in the sample that are part of the treatment group. Finally, we obtain the IPW estimate of the effect of railway access on the change in outcome from four periods before the line opened to τ periods thereafter by comparing means of the re-weighted data: $\hat{\gamma}_{att,\tau,IPW} = \hat{\mathbb{E}}[\hat{w}_i \cdot \Delta y_{ijt}^{\tau}]$. Here, $\Delta y_{ijt}^{\tau} = y_{ijt}^{t+\tau} - y_{ijt}^{t-4}$ is the change in outcome y between period $t-4$ and $t+\tau$ for a parish i. As before, τ are the time periods since the (case-specific) railway line's opening year t. We compute estimates $\hat{\gamma}_{att,\tau,IPW}$ for $\tau = -3, ..., 13$ with $\tau = 0$ corresponding to the year of railway access.

Inverse probability weighting regression adjustment. The IPWRA model uses $\hat{w}_i$ from equation (A-2) to run weighted regressions of Δy_{ijt}^{τ} on our set of covariates. These regressions are estimated separately for treated and control parishes. Specifically, we estimate parameters (α_0, ω_0) and (α_1, ω_1) by solving the following weighted least squares problems:

$$\min_{\alpha_0,\omega_0} (1 - D_{ij,1855})\hat{w}_i(\Delta y_{ijt}^{\tau} - \alpha_0 - \omega_0 \boldsymbol{X}_i)^2,$$

$$\min_{\alpha_1,\omega_1} D_{ij,1855}\hat{w}_i(\Delta y_{ijt}^{\tau} - \alpha_1 - \omega_1 \boldsymbol{X}_i)^2.$$

The IPWRA estimate is then given by the average of the difference in predicted values, as evaluated for the sub-population of parishes with railway access:

$$\hat{\tau}_{att,\tau,IPWRA} = \hat{\mathbb{E}}\left[(\hat{\alpha}_1 - \hat{\omega}_1 \boldsymbol{X}_i) - \hat{\alpha}_0 - \hat{\omega}_0 \boldsymbol{X}_i) \mid D_{ij,1855} = 1\right].$$

Appendix 10 Overlap assumption

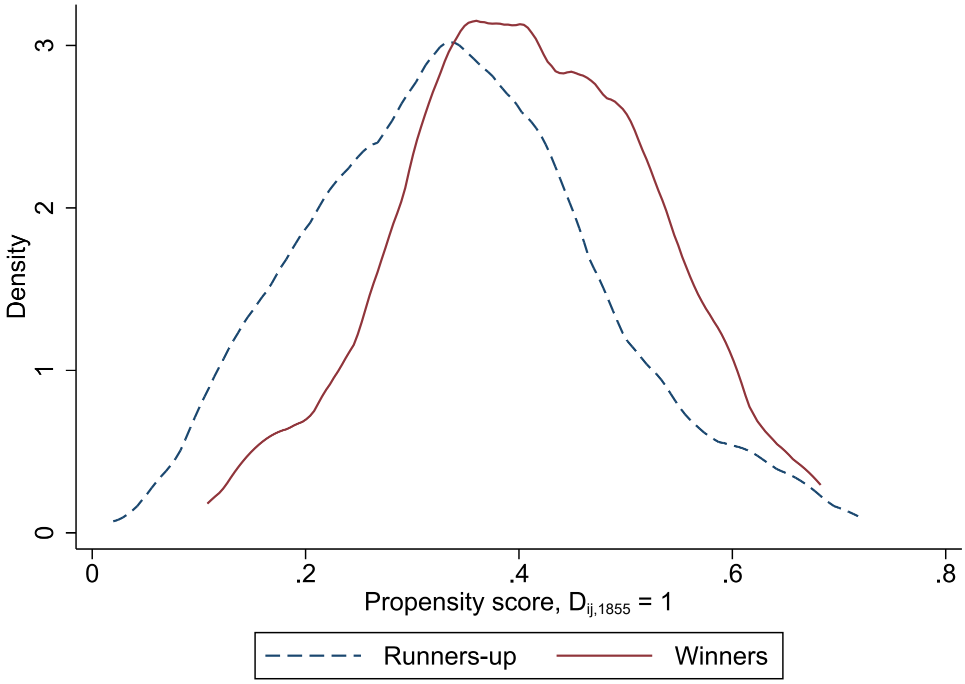

Figure A-7: Smoothed density for the estimated propensity for railway access in the first construction stage

Notes: The figure shows smoothed densities of the estimated propensities for railway access in the first construction stage both for winners (solid line) and runners-up (dashed line). The explanatory variables are log population and log population density in 1834, the share of protestants in 1821, a dummy for having a manufactory in 1832, industry employment per 100 persons in 1829, elevation, dummies for access to a navigable river in 1845 and to a road in 1848, and case dummies. We smooth the densities using an Epanechnikov kernel.

Source: Authors' calculations.

Appendix 11 Semi-parametric estimates for population growth, winner versus runners-up sample

Figure A-8 shows the results from semi-parametric IPW and IPWRA of the effect of railway access on population growth for the winner versus runners-up sample. The dependent variable is the change in log population between period $t-4$ and period $t+\tau$ where t is the time when a case's winning line was opened. The effect of railway access on the change in log population is thus normalized to zero for $\tau = -4$.

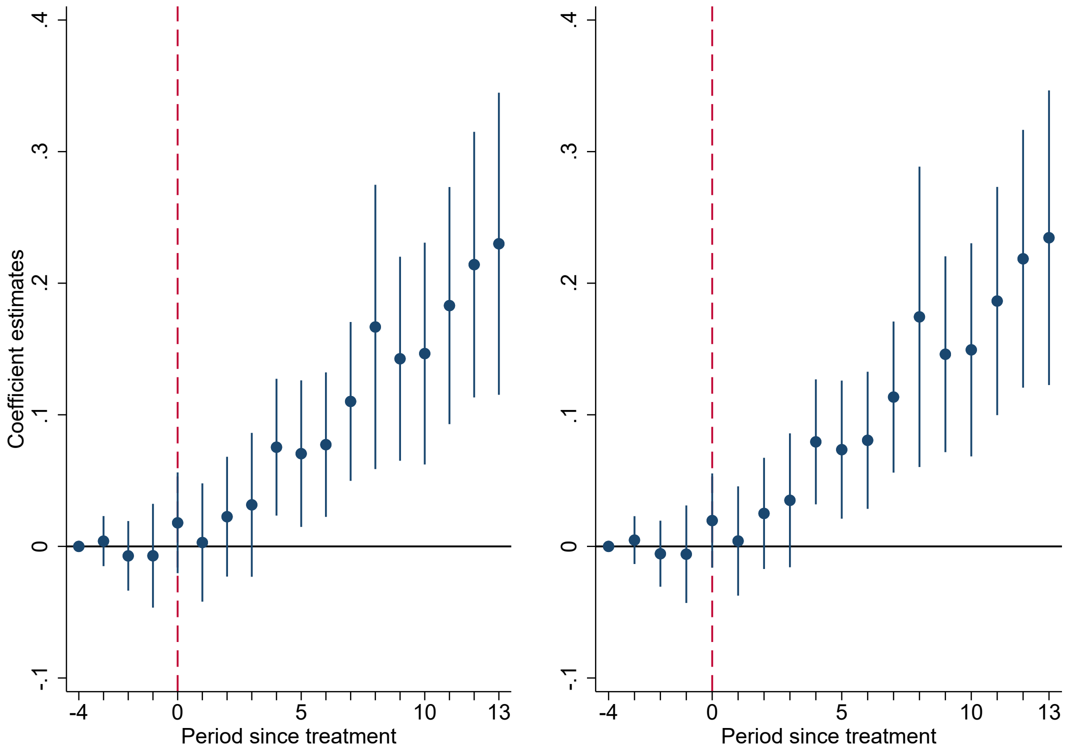

Figure A-8: Semi-parametric estimates of the effect of railway access on log population

Notes: This figure plots semi-parametric estimates of the effect of railway access in 1845–54 on log population. The dependent variable is the change in log population since the fourth period before the treatment. The left panel shows estimates from inverse probability weighting (IPW), the right panel from inverse probability weighting regression adjustment (IPWRA). Point estimates are marked by a dot. The vertical bands indicate the 95 percent confidence interval of each estimate. The red dashed vertical line indicates the treatment period.
Sources: Data on Population are from Statistisches Landesamt Baden-Württemberg (2008).

The figure depicts estimates for $\tau = -4, -3, ..., 13$. Dots mark the point estimates, vertical bands the corresponding 95 percent confidence intervals. Reassuringly, we see no differential population trends between winner and runner-up parishes before the arrival of the railway. Thereafter, log population gradually increases in winner parishes in both IPW and IPWRA estimations. After thirteen periods, the cumulative effect of railway access on population reaches 0.229 and 0.234 log points in the IPW and IPWRA estimation, respectively. Semi-parametric estimates are thus very similar to our event study results in the Subsection "Population growth". Figure A-9 additionally compares the event study results from Figure 3 in the main text to cross-sectional IPWRA estimates, which use the population *level* rather than the *change in population* relative to the baseline period as outcome variable. Both models again yield very similar results for the over-time effect of railway access on population.

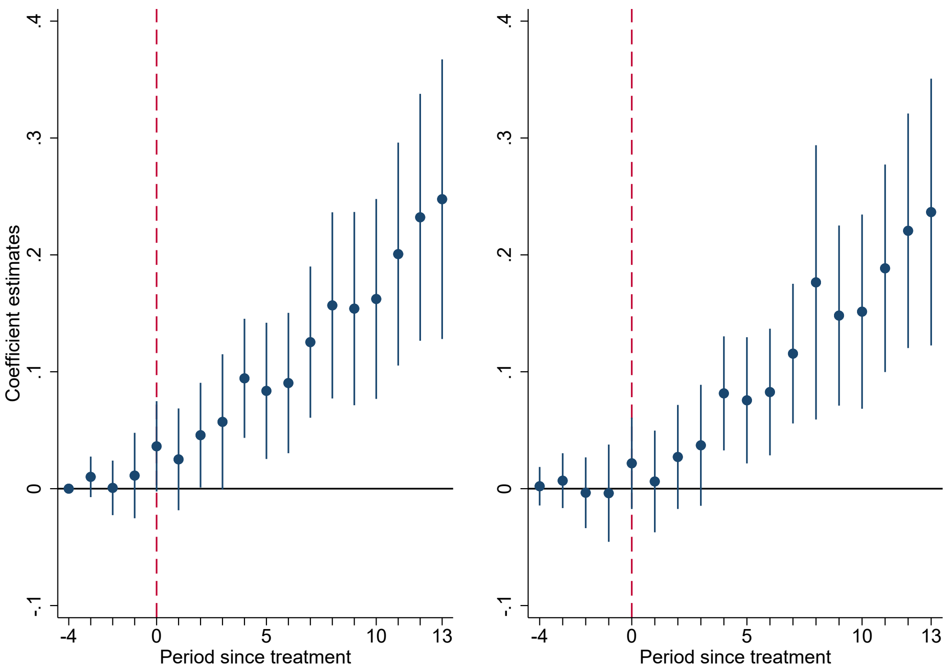

Figure A-9: Event study and cross sectional IPWRA estimates

Notes: The graph depicts differences in log population between winner and runner-up parishes. The left panel replicates Figure 3, that is, the difference in log population for pre- and post-treatment periods, as estimated in an event study regression. Differences are expressed relative to the baseline differences four periods before the treatment. The right panel shows cross sectional estimates from inverse probability weighting regression adjustment (IPWRA) with log population as dependent variable. Each point estimate shows the difference in log population for a cross section in pre- and post-treatment periods τ = -4,-3,...,13. Point estimates are marked by a dot. The vertical bands indicate the 95 percent confidence interval of each estimate. The red dashed vertical line indicates the treatment period.
Sources: Data on population are from Statistisches Landesamt Baden-Württemberg (2008).

Appendix 12 Event study and semi-parametric estimates for population growth, full sample

Event-study and semi-parametric estimates for the winners versus runners-up sample in Subsection "Population growth" shows that much of the positive effect of railway access on population growth materializes decades after the treatment. This Appendix shows that we reach similar conclusion for the full sample as well.

Appendix Figure A-10 compares over time differences in population between railway and non-railway parishes for the full sample, based on panel fixed effects regression. The 'period since treatment' is not defined for non-railway parishes that were not runners-up for a railway line. We thus instead compare differences between railway and non-railway parishes over time, taking 1834 as the baseline year. Consequently, results for the full sample are not directly comparable to those for the winner versus runners-up sample reported in Subsection "Population growth". They nevertheless show a similar picture, with population differences gradually growing over time. In fact, Figure A-10 shows that the widening of the population gap between railway and non-railway parishes accelerated in the 1890s and 1900s, long after parishes first got access to the railway. Semi-parametric IPW and IPWRA estimates yield very similar conclusions (see Figure A-11).

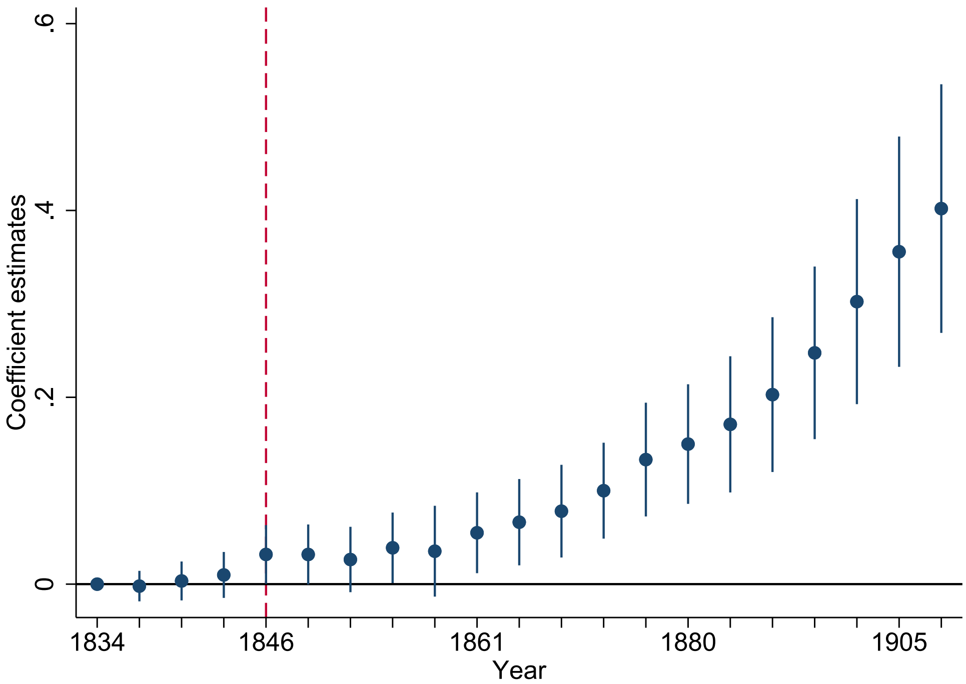

Figure A-10: Event study estimates, full sample

Notes: The graph depicts differences in log population between railway and non-railway parishes in 1837–1910, as estimated in a panel regression with parish fixed effects. 1834 serves as baseline period. Point estimates are marked by a dot. The vertical bands indicate the 95 percent confidence interval of each estimate. The red dashed vertical line indicates the treatment period.

Sources: Data on population are from Statistisches Landesamt Baden-Württemberg (2008).

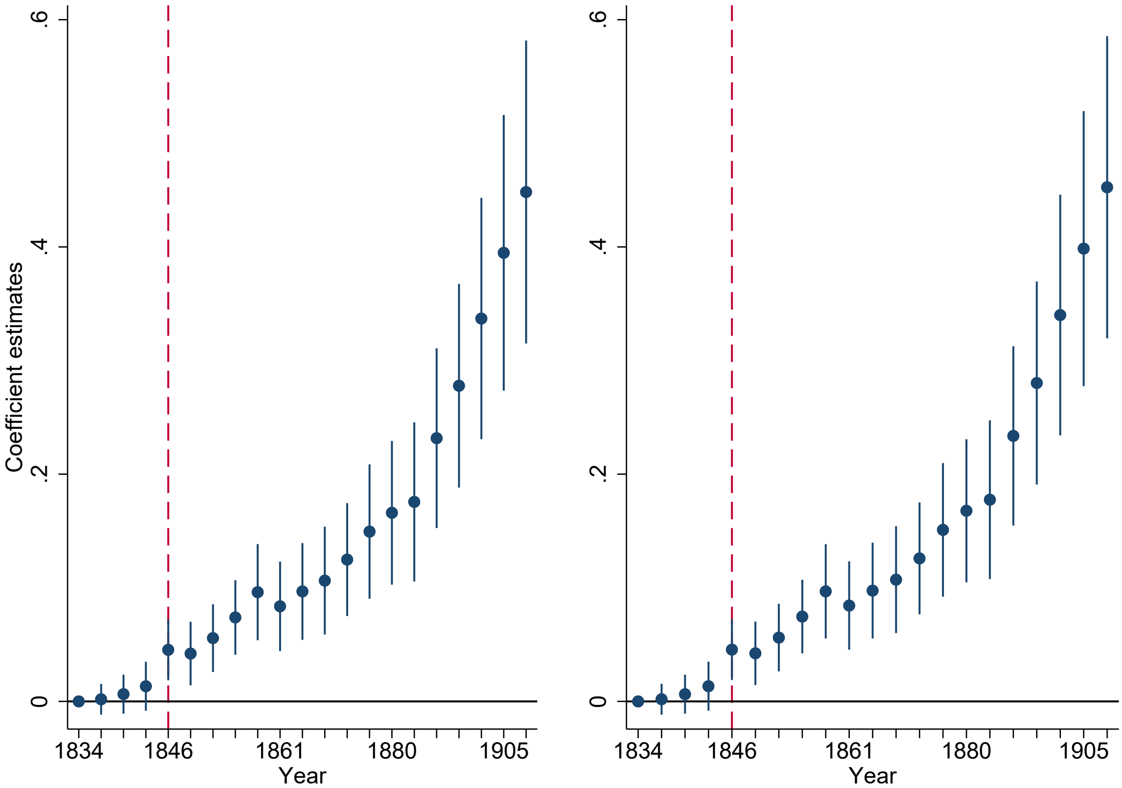

Figure A-11: Semi-parametric estimates of the over time effect of railway access on log population, full sample

Notes: This figure plots semi-parametric estimates of the effect of railway access in 1845–54 on log population. The dependent variable is the change in log population since 1834. The left panel shows estimates from inverse probability weighting (IPW), the right panel from inverse probability weighting regression adjustment (IPWRA). Point estimates are marked by a dot. The vertical bands indicate the 95 percent confidence interval of each estimate. The red dashed vertical line indicates the treatment period.

Sources: Data on population are from Statistisches Landesamt Baden-Württemberg (2008).

Appendix 13 Natural population growth versus immigration

We have established in the main text that railway access had a sizable and lasting positive effect on parish level population. Such population increase could be driven by immigration and/or changes in the rate of natural population increase (in other words, an increasing birth rate and/or a decreasing death rate). Census data for 1871, 1895 and 1900 tentatively suggest that railway access indeed induced immigration to winner parishes. For all three years, we regress the share of inhabitants born outside of a parish (hereafter: foreign-born) on the treatment group dummy and our usual set of control variables (we cannot run panel regressions as we do not have pre-treatment information on the share of foreign-born). IPW and IPWRA estimations suggest that railway access increased the population share of foreign-born inhabitants by 5.8 percentage points in 1871 (from a baseline of 24.5 percent), by 6.3 percentage points in 1895 (from a baseline of 28.9 percent), and by 6.0 percentage points in 1900 (from a baseline of 30.9 percent). OLS regressions yield virtually identical results (see again Table A-5 for details).

Data for 1871 additionally distinguishes between foreign-born who were born a) in a different parish in Württemberg, b) in a member state of the German Customs Union (except Württemberg), and c) abroad. Much of the differences in the share of the foreign-born between winner and runner-up parishes is driven by migration within Württemberg: the (unconditional) population share of foreign-born who are originally from another parish in Württemberg is 28.1 percent in winning parishes but only 23.0 percent in losing parishes. Population growth in winner parishes was thus–at least in part–due to relocation within Württemberg. Migration across state borders was much less important: Only 0.5 percent of individuals in our winners versus runners-up sample were born abroad in 1871. Yet, the average population share of migrants born abroad is three times higher in winning parishes (0.6 percent) compared to losing parishes (0.2 percent)–and such differences might have become more important over time.[4]

[4]Data on immigration is not consistent over time, as the different censuses use very different definitions. The

Table A-5: The effect of railway access on the share of foreign-born and the rate of natural population increase

	Share of foreign born			Fertility rate	Mortality rate	Rate of nat. increase
	1871	1895	1900	1871–1910	1871–1910	1871–1910
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: IPW						
Treatment effect	0.058***	0.063***	0.060***	-0.303	-0.174	-0.129
	(0.016)	(0.015)	(0.018)	(0.983)	(0.788)	(0.899)
Panel B: IPWRA						
Treatment effect	0.057***	0.062***	0.059***	-0.172	-0.180	0.008
	(0.016)	(0.015)	(0.017)	(0.942)	(0.792)	(0.892)
Panel C: OLS						
Treatment effect	0.059***	0.066***	0.065***	-0.072	-0.548	0.475
	(0.015)	(0.015)	(0.017)	(0.976)	(0.673)	(0.805)
Observations	156	156	156	152	152	152
Control mean	0.245	0.289	0.309	37.65	26.26	11.39

Notes: The table shows regression estimates of the effect of railway access in 1845–54 on the share of inhabitants born outside a parish in 1871 (Column (1)), 1895 (Column (2)) and 1900 (Column (3)), and on the annual number of birth (Column (4)), death (Column (5)) and natural population increase (Column (6)) per 1,000 inhabitants, averaged for 1871–1910. The regressions in Panel A are estimated by IPW, regressions in Panel B by IPWRA and regressions in Panel C by OLS. All regressions include as control variables log population and log population density in 1834, the share of protestants in 1821, a dummy for having a manufactory in 1832, industry employment per 100 persons in 1829, elevation, dummies for access to a navigable river in 1845 and to a road in 1848, and case dummies. Robust standard errors are in parentheses. ***, **, and * denote statistical significance at the 1, 5, and 10 percent level, respectively.
Sources: Data are from Statistisches Landesamt Baden-Württemberg (2008).

We also use annual data on the number of births and deaths between 1871 and 1910 to estimate OLS and semi-parametric models with the average annual birth rate, death rate and rate of natural population increase as dependent variables. The results indicate that there is no statistically significant difference in fertility and mortality rates between winners and runners-up in 1871–1910 (see Table A-5 for details). Finally, we also use the vital statistics to calculate the hypothetical average annual parish level population growth in 1871–1910 had population only changed through net migration (in other words, average annual population growth net of natural population increase). Appendix Figure A-12 shows this hypothetical growth rate,

last census in our sample from 1910 recorded the number of individuals without German citizenship. The average share is 1.4 percent in winning parishes and 0.8 percent in losing parishes.

along with Württemberg's railway network in 1855. The figure indicates that migration-induced population growth was indeed higher in parishes along the railway network.[5] We thus conclude that the positive effect of the railway on population growth in winner parishes is mainly driven by immigration, in line with spatial equilibrium models.

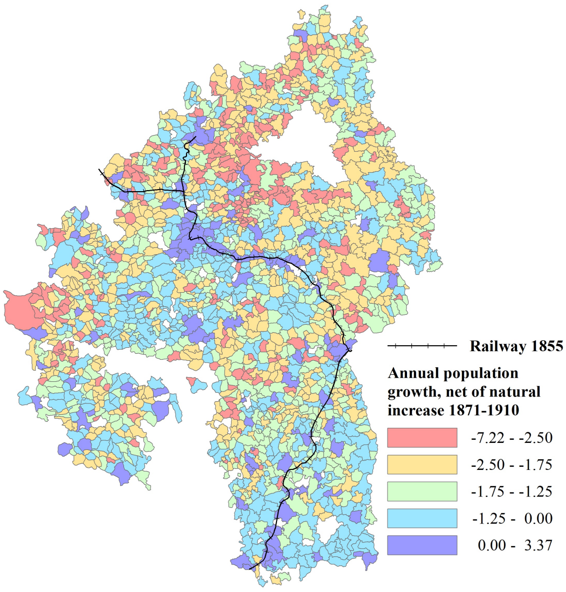

Figure A-12: Average annual population growth in 1871–1910, net of natural population increases

Notes: The figure shows the hypothetical average annual parish level population growth in 1871–1910 had population only changed through net migration (in other words, average annual population growth net of natural population increase). The solid black line depicts the railway network in 1855. Data on vital statistics are missing for the district of Hall and a few other parishes.
Sources: Kunz and Zipf (2008), Dumjahn (1984), Kommission für geschichtliche Landeskunde in Baden-Württemberg and Landesvermessungsamt Baden-Württemberg (1972). Authors' design.

[5]The figure suggests that net emigration rates were highest in the northwest of the country. Most historical accounts explain this pattern with the poor soil quality in the northwest of Württemberg (von Hippel 1984). Moreover, the cultivation of potatoes and wine in the north-west of Württemberg was more susceptible to crop failures than the traditional grain cultivation in the east. This led to higher emigration during hunger crises.

Appendix 14 The effect of gaining railway access in later construction stages

As it is common in the literature (see, for example, Berger and Enflo 2017; Hornung 2015), our analysis focuses on *early* railway connections. In particular, we focus on the effect of gaining access to the railway in the first construction stage from 1845 to 1854. However, a significant number of parishes that did not get access to the railway in the first construction stage did get access in the second stage from 1857 to 1886. In fact, the second stage was of major importance for Württemberg's railway network: It expanded its length from 290 to 1,560 kilometers and increased the number of parishes with railway access from 73 to 350. Figure A-13 shows the share of winners, runners-up, and 'non-railway' parishes with access to the railway over time. This subsection studies whether gaining railway access in later construction stages had similar effects on population as those that we document for the first stage.

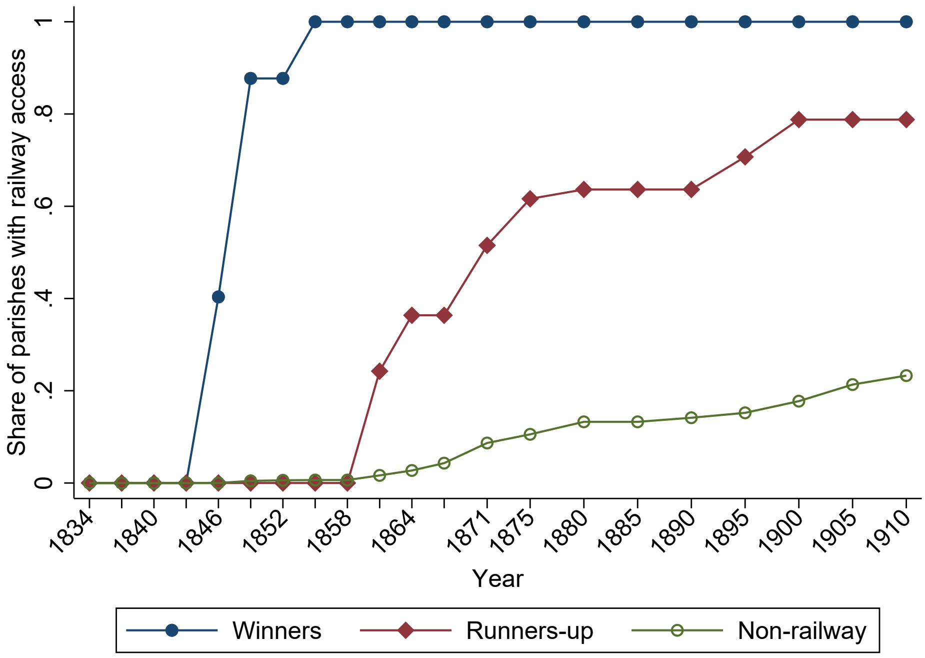

Figure A-13: Share of parishes with railway access by winners, runners-up, and non-railway parishes, 1834–1910

Notes: The figure shows the share of parishes with railway access for winners, runners-up, and non-railway parishes by year.
Sources: Dumjahn (1984), Wolff and Menges (1995), Königliches Statistisches Landesamt (1911). Authors' design.

Table A-6 replicates the results from our baseline specifications (from Table 2 in the main text), adding a separate treatment indicator for the second construction stage to equation (1).[6] Columns (1) and (2) restrict the sample to winner and runner-up parishes. Of the 99 runner-up parishes, 61 parishes–or 62 percent–gained access to the railway in the second construction phase (see Appendix Figure A-13). Our estimates suggest, however, that these parishes did not grow faster than parishes that remained without access by 1886.[7] This also implies that runner-up parishes did not catch up to the winner parishes even if they later gained access to the railway themselves.

Table A-6: Panel estimates of the effect of early and late railway access on population

	Winners vs. runners-up		Full sample		
	(1)	(2)	(3)	(4)	(5)
Railway access 1845–54	0.106***	0.116***	0.180***	0.142***	0.143***
	(0.030)	(0.028)	(0.024)	(0.023)	(0.023)
Railway access 1857–86	-0.029	-0.059*	0.095***	0.112***	0.113***
	(0.034)	(0.035)	(0.011)	(0.010)	(0.010)
Railway access 1887–1910					0.054***
					(0.020)
Observations	3,276	3,276	38,766	38,766	38,766
Parish FE	Yes	Yes	Yes	Yes	Yes
Year × Case/County FE	No	Yes	No	Yes	Yes

Notes: The table shows panel regression estimates of the effect of railway access in the first, second, and third construction phase (1845–54, 1857–86 and 1887–1910) on log population. Regressions (1) and (2) are estimated for the winners versus runners-up sample, regressions (3) to (5) for the complete sample excluding railway nodes. All regressions include a full set of year and parish dummies. Regression (2) additionally includes year-by-case fixed effects and regressions (4) and (5) include year-by-county fixed effects. Standard errors clustered at the parish level are in parentheses. ***, **, and * denote statistical significance at the 1, 5, and 10 percent level, respectively.
Sources: Population data are from Statistisches Landesamt Baden-Württemberg (2008).

[6] Let $D_{i,1886}$ be a binary treatment indicator that indicates whether parish i was connected to the railway between 1857 and 1886 (and not earlier, later or never), and let $1(\kappa \geq 0)_{it}$ be a dummy that indicates whether parish i had railway access at time t. The treatment indicator for the second construction stage is $D_{i,1886} \times 1(\kappa \geq 0)_{it}$.

[7] An important shortcoming of these regressions is that runner-up parishes that did not gain railway access by 1886 are likely to be a selected group of all runner-up parishes. In fact, runner-up parishes that did not get access in the second stage were statistically significantly smaller in 1855 than runner-up parishes that gained access in 1857–86 (difference in log population is 0.28 with a s.e. of 0.14). This selection should, however, bias the estimated impact of later rail connections upward and can thus not explain our 'no effect finding'.

The fact that later railway access did not boost population in the winner vs. runner-up sample may seem surprising. After all, the second construction stage connected major towns to the network, such as Reutlingen or Tübingen, which had remained without access after the first stage. However, our winners versus runners-up sample does not capture the most important new lines that were added to the network in 1857–86 (such as the railway line connecting Plochingen with Reutlingen and Tübingen). This is because the runner-up parishes are located along alternative routes between major towns, which had already been connected in the first construction stage. Building these initially unrealized 'alternative routes' later did not boost population along the way, probably precisely because the winning lines were already in operation.

This interpretation is strengthened by our findings for the full sample, reported in Columns (3) and (4) of Table A-6. Of the 1,786 parishes that did not get railway access in the first construction stage, 277 did so in 1857–86. The estimates suggest that in the full sample, late railway access indeed increased population. The effect is sizable but somewhat smaller than for early railway access (0.095–0.112 compared to 0.142–0.180 log points). This is not surprising since the lines built in the first construction phase were arguably the most important ones, especially for transit passengers and freight. The estimated effect of early railway access on population is slightly larger in Table A-6 than in our baseline regressions in Table 2. This is because in later years, parishes that gained access in 1857–1886 are no longer in the control group in Table A-6 (and these parishes grew faster themselves). Yet, differences are small, as the majority of parishes remained without railway access by 1886.

In the full sample, we can also study the effect of the third construction stage from 1887 onwards, which connected mostly rural parishes via branch lines to the main network. Of the 1,509 parishes that did not get railway access until 1886, 173 did so in 1887–1910. Column (5) adds separate treatment indicators for the second and third construction stage to our full-fledged specification with parish and year-by-county fixed effects. The estimates suggest that the third construction stage still had a positive effect on population, but that the effect was considerably smaller than for the first two stages. The decreasing effect size presumably reflect the lower importance, in terms of passengers and freight, of the lines that were built later.

Appendix 15 Localized displacement

This subsection describes our results on localized displacement effects in greater detail. Following Büchel and Kyburz (2020), we estimate local polynomial regressions of residual outcomes on log distance (in meters) to the nearest railway parish in 1855. Under the assumption that railways had no effect on distant parishes, the resulting spatial pattern should be hump-shaped if railways indeed cause reorganization (see also Berger and Enflo 2017; Bogart et al. 2022). We use the full sample for this analysis since the winners vs. runners-up sample exhibits too little variation in the distance to railway parishes for the analysis to be meaningful.

Figure A-14 shows the results for six different outcome variables, namely for the population ratio 1843 to 1834 (Graph (a)), the population ratio 1910 to 1855 (Graph (b)), the average annual income in 1907 in *Mark* (Graph (c)), the building value in 1907 in *Mark* (Graph (d)), and the number of full-time employees in industry per 100 persons in 1829 and 1907 (Graphs (e) and (f)). Residuals come from OLS regressions of the outcome variables on log population and log population density in 1834, the share of protestants in 1821, a dummy for having a manufactory in 1832, industry employment per 100 persons in 1829 (except Graph (e)), elevation, dummies for access to a navigable river in 1845 and to a road in 1848, and district dummies. Reassuringly, the residuals for pre-treatment outcomes, the population ratio 1843 to 1834 and industry employment in 1829, are uncorrelated with the distance to railway parishes in 1855.

In line with our empirical analysis, Graph (b) of Figure A-14 shows that population growth in 1855–1910 was considerably stronger in parishes close to the railway than in those further away. However, population growth in parishes with railway access did not come only–or even predominantly–at the expense of nearby parishes. Our results for income, housing values, and industrial employment are broadly consistent with our results for population growth. While income and housing values show a small trough at medium distances, industry employment falls monotonically with distance to railway parishes. Overall, we find little evidence for localized

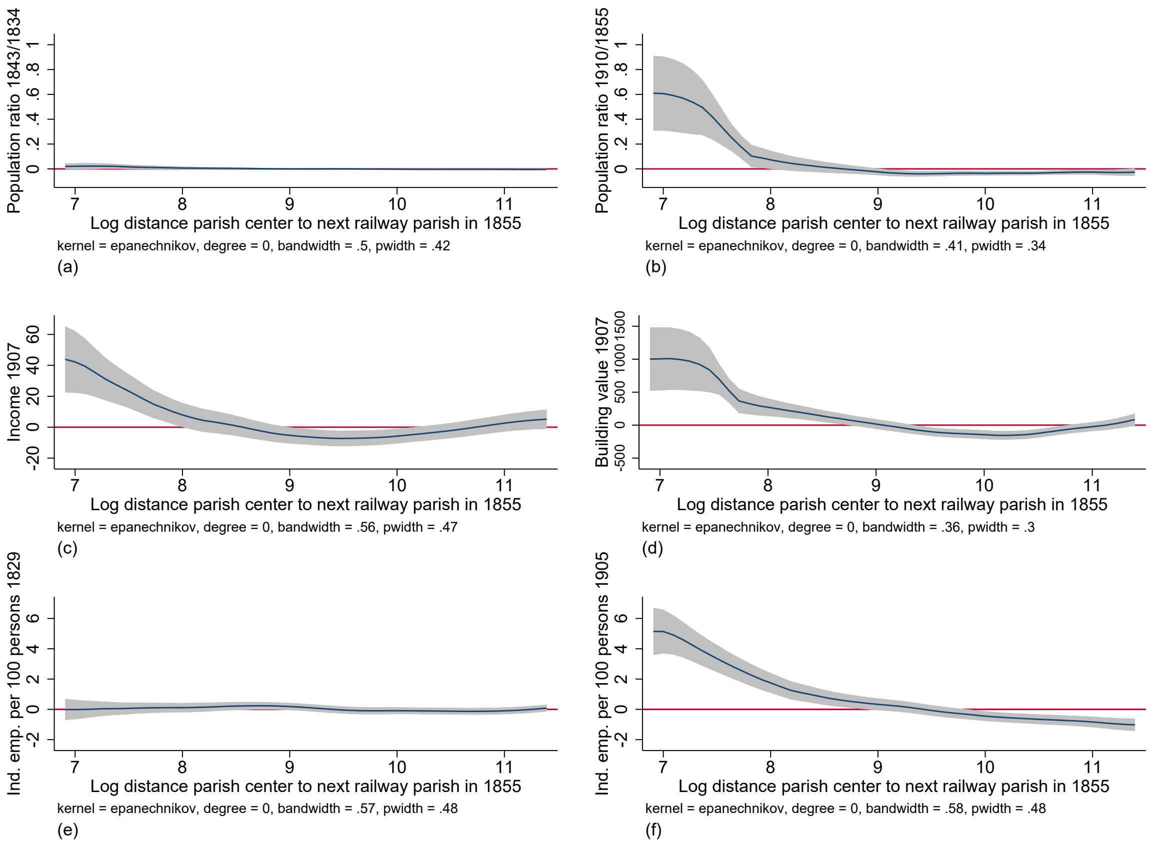

Figure A-14: Polynomial estimates, full sample

Notes: Each graph shows smooth values with 95 percent confidence band from kernel-weighted local polynomial regression of outcome residuals on log distance of parish centroids to the nearest railway parish in 1855. We add 1000 meters to all distances to avoid zero distances and smooth values close to zero. The outcome variables are the population ratio 1843 to 1834 (Graph (a)), the population ratio 1910 to 1855 (Graph (b)), the average annual income in 1907 in *Mark* (Graph (c)), the building value in 1907 in *Mark* (Graph (d)), and the number of full-time employees in industry per 100 persons in 1829 and in 1907 (Graphs (e) and (f)). We take the residuals from OLS regressions of outcome variables on log population and log population density in 1834, the share of protestants in 1821, a dummy for having a manufactory in 1832, industry employment per 100 persons in 1829 (except Graph (e)), elevation, dummies for access to a navigable river in 1845 and to a road in 1848, and district dummies as explanatory variables.

Sources: Population is from Statistisches Landesamt Baden-Württemberg (2008). Taxable income and building tax revenues in 1907 are from Königliches Statistisches Landesamt (1910). Employment data are from the occupation census of 1907 (Königliches Statistisches Landesamt 1900a, 1910) and the *Gewerbestatistik* of 1829 (various volumes of *Gewerbekataster*, Staatsarchiv Ludwigsburg E 258 VI).

displacement effects.

One potential explanation for the lack of displacement effects is that nearby parishes were not well integrated, possibly because of Württemberg's hilly topography or the restrictions placed on settlement rights until the 1860s (von Hippel 1992). Another explanation holds that the railway facilitated particularly the recruitment of workers from further afield. Ziegler (1996), for instance, argues that the movement of Polish workers to the Ruhr valley would not have been possible without the railway, in contrast to the immigration from nearby Westphalia. Positive spill-overs, as documented by Hornung (2015) for Prussia, might also have outweighed potential displacement effects. Unfortunately, our data do not allow us to distinguish between these explanations.

We also caution that the cross-sectional regressions in Figure A-14 will only be informative about the "pure" growth effects of railway infrastructure if far-away regions–or some "residual regions" more generally–are unaffected by the treatment (Redding and Turner 2015). This assumption might be questionable, especially in our context of a nation-wide infrastructure project. For instance, Subsection "Population growth" suggests that immigration from within Württemberg was important for the positive effect of railways on population growth in winner parishes. In this context, Graph (b) of Figure A-14 only clarifies that the relocation of population within Würrtemberg did not come solely at the expense of parishes in the immediate vicinity of the railway.

Appendix 16 Württemberg's location of iron and steel production 1834 and 1895

Appendix Figure A-15 shows parish-level employment in Württemberg's iron and steel production (per 100 persons) in 1834 and 1895. In 1834, 23 parishes reported positive employment levels in iron and steel production. Eight of them had at least one worker per 100 persons employed in the sector. Württemberg's iron and steel production clustered around the iron ore deposits in the black forest and the Swabian Alp. Railway construction initially increased demand for Württemberg's iron and steel (von Hippel 1992), and iron ore mining for the production of iron reached its peak in the late 1850s (Plumpe 1982).

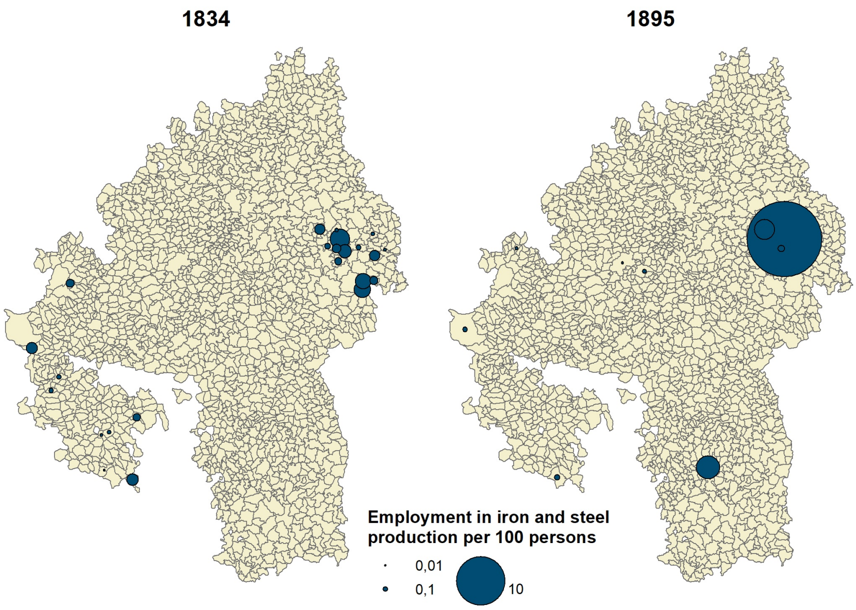

Figure A-15: Employment in iron and steel production, 1834 and 1895 (per 100 persons)

Notes: The figure shows parish-level employment per 100 persons in iron and steel production (*Herstellung von Eisen und Stahl, Frisch- und Streckwaren*)
Sources: Württemberg's *Gewerbestatistik* of 1829 (various volumes of *Gewerbekataster*, Staatsarchiv Ludwigsburg E 258 VI) and 1895 (Königliches Statistisches Landesamt 1900b). Authors' design.

However, Württemberg's charcoal pig iron could less and less compete with the cheaper coke pig iron produced in the Ruhr and Saar regions. The availability of wood, historically a significant locational advantage of Württemberg's iron producer, lost importance. Between 1870 and 1895, Württemberg's iron and steel production plummeted from 1% of Germany's overall production to just 0.2% (von Hippel 1992).[8] By 1895, only nine parishes still reported positive employment levels in iron and steel production, and only three of them had employment levels of one or more worker per 100 persons. The royal smelting works (*königliche Hüttenwerke*) Wasseralfingen gained a dominant position since the 1850s when it developed into a vertically integrated plant that combined iron ore mining, pig iron production, and iron processing. However, after production peaked in 1873, total output declined and Wasseralfingen's blast furnace finally closed in 1925 (Plumpe 1982).

Appendix 17 Effect heterogeneity by railway line

This subsection tests for effect heterogeneity by railway line, distinguishing between the northern line (Stuttgart-Bietigheim-Heilbronn/Bretten), the eastern line (Stuttgart-Esslingen-Ulm) and the southern line (Ulm-Friedrichshafen) (see Figure A-16). The eastern line formed arguably the core of the network. It connected the densely populated Neckar basin, where much of the important textile industry was concentrated already before the railway era (Feyer 1973), with Ulm, Württemberg's second largest town. It is thus not surprising that the eastern line was the busiest section of Württemberg's railway network, benefiting also from the transit traffic between Baden and Bavaria. The southern line from Ulm to Friedrichshafen, in contrast, was much less frequented as it served the sparsely populated and hardly industrialized south-east of Württemberg.[9] We thus expect that parishes along the eastern line benefited more from the

[8]Likewise, Plumpe (1982) reports that Württemberg's share in Germany's pig iron production fell from 1.0% in 1871 to 0.1% in 1894. At the same time, Prussia's share increased from 62% to 77%.

[9]Transport statistics from 1868/69 illustrate the difference between the lines (Königliches Statistisches Landesamt 1874). Looking at internal freight with origin and destination in Württemberg, railways transported 4,487,810 centners per mile per year on the eastern line but only 2,106,534 centners on the northern, and 1,903,806 centners on the southern line. Differences are even more striking if we consider freight with origin and/or destination outside Wüttemberg. Such freight amounted to 4,277,782 and 4,765,137 centners on the eastern and northern line, respectively, but to only 480,872 centners on the southern line.

railway than those along the southern line.

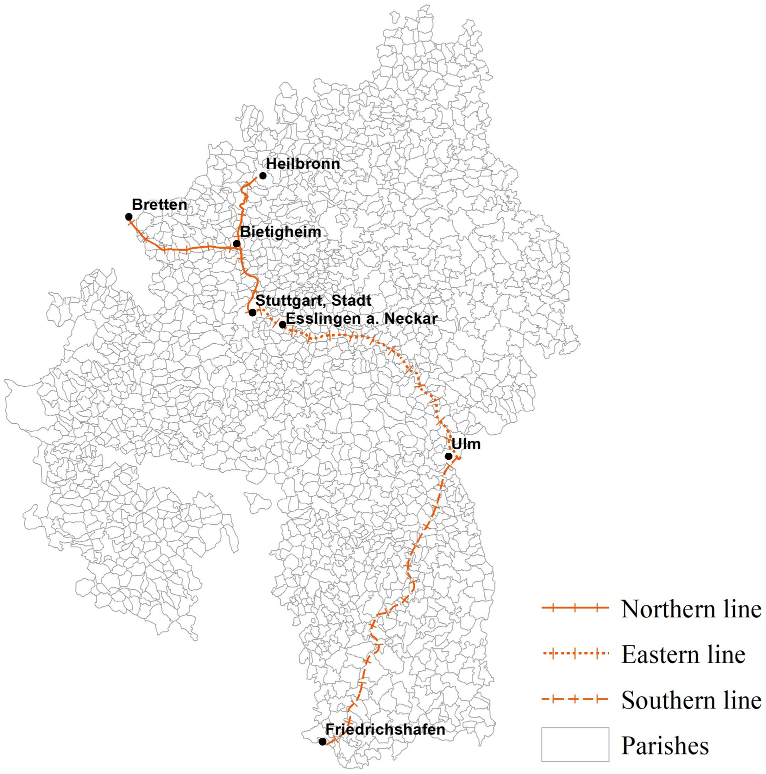

Figure A-16: Northern, eastern and southern line of the railway network in Württemberg 1855

Notes: The figure shows the northern (solid line), eastern (dotted line), and southern railway line (dashed line) of the railway network in Württemberg in 1855.

Sources: Kunz and Zipf (2008), Dumjahn (1984), Kommission für geschichtliche Landeskunde in Baden-Württemberg and Landesvermessungsamt Baden-Württemberg (1972), Statistisches Landesamt Baden-Württemberg (2008). Authors' design.

Table A-7: Heterogeneous effects of railway access by railway line

	Population	Day laborer wage (*Pfennig*)		Taxable income (*Mark*)	Building value (*Mark*)	Fire insurance value (*Mark*)	Industry employment		Establishment size (logs)	Steam engine	
		Female	Male							(0/1)	HP pc
	1834–1910	1909	1909	1907	1907	1908	1895	1907	1895	1869	1869
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Treatment dummy	0.009***	14.959***	26.236***	117.623***	2,207.0***	2,887.5***	9.745***	10.752***	0.842***	0.419***	20.916**
	(0.001)	(2.973)	(3.836)	(21.927)	(482.5)	(669.2)	(1.822)	(1.724)	(0.180)	(0.132)	(9.785)
Treatment dummy ×											
Northern line	-0.001	2.522	-5.130	-58.645*	-1,169.1*	-1,811.9**	-3.926	-4.586**	-0.382*	-0.210	-19.789**
	(0.002)	(4.704)	(8.272)	(29.985)	(695.9)	(835.4)	(2.439)	(2.186)	(0.221)	(0.174)	(9.811)
Southern line	- 0.006***	-16.598***	-23.651***	-103.051***	-1,664.3***	-2,220.6***	-7.492***	-6.834***	-0.697***	-0.333**	-20.468**
	(0.002)	(4.025)	(6.718)	(26.715)	(498.9)	(709.0)	(2.039)	(1.963)	(0.197)	(0.151)	(9.726)
Observations	38,766	1,843	1,843	1,843	1,843	1,843	3,692	3,686	3,318	3,692	3,692

Notes: The table shows regression estimates of the effect of railway access in 1845–54–and its interaction with location along the northern and southern line–on population (Column (1)), the average daily wage of female (Column (2)) and male (Column (3)) day laborers in 1909, on taxable income per capita in 1907 (Column (4)), the average value of buildings in 1907 (Column (5)), the average fire insurance value per building in 1908 (Column (6)), the number of full-time employees in industry per 100 persons in 1895 and 1907 (Columns (7) and (8)), establishment size in industry in 1895 (Column (9)), the probability of having installed at least one steam engine by 1869 (Column (10)), and steam horsepower per 1,000 persons in 1869 (Column (11)). Estimates in Columns (1) and (7) to (11) are from panel fixed effects regression that include parish and year-by-county fixed effects. Specification (1) assumes that the treatment effect is a linear time break. Estimates in Columns (2) to (6) are from cross-sectional OLS regressions. Control variables in these regressions include log population and log population density in 1834, the share of protestants in 1821, a dummy for having a manufactory in 1832, industry employment per 100 persons in 1829, elevation, dummies for access to a navigable river in 1845 and to a road in 1848, a dummy indicating whether population in the main location of residence in 1843 was above the treatment group median, and dummies for geographic location within Württemberg. Robust standard errors are in parentheses. ***, **, and * denote statistical significance at the 1, 5, and 10 percent level, respectively.

Sources: The average daily wage of day laborers in 1909, taxable income and building value in 1907, and the fire insurance value of buildings in 1908 are from Königliches Statistisches Landesamt (1910). Employment data are from the occupation censuses of 1895 and 1907 (Königliches Statistisches Landesamt 1900a, 1910) and the *Gewerbestatistik* of 1829 (various volumes of *Gewerbekataster*, Staatsarchiv Ludwigsburg E 258 VI) and 1895 (Königliches Statistisches Landesamt 1900b). Data on the location of steam engines are from archival records (Staatsarchiv Ludwigsburg E 170 Bü 272).

Consistent with our conjecture, estimates in Column (1) show that railway access increased population growth much more strongly along the eastern than along the southern line. Annual population growth increased by 0.9 percentage points in parishes along the eastern line but by only 0.3 percentage points in parishes along the southern line. The railway thus reinforced pre-existing population differences between Württemberg's densely populated Neckar basin and the sparsely populated southwest.

Columns (2) to (6) tests for heterogeneity in the effect of railway access on wages, income and housing values. We again find strong and precisely estimated differences between parishes located along the eastern and southern line. As a point in case, we find no statistically significant effect of railway access on wages of day laborers for parishes along the southern line. In contrast, access increased female and male day laborer wages along the eastern line by 14.96 and 26.24 *Pfennig*, respectively (or 9.0 and 10.6 percent relative to the control mean).

Finally, Columns (7) to (11) reveal that railway access also had strikingly different effects on industrial development. For instance, we find that by 1895, railway access had increased industry employment by 9.7 employees per 100 persons along the eastern but by only 2.3 employees along the southern line. Likewise, access increased the probability of adopting a steam engine by almost 42 percentage points along the eastern line but by only 8.6 points along the southern line. The railway thus increased disparities between Württemberg's more and less industrialized regions.

Appendix 18 Additional results for the winner versus runners-up sample

Table A-8: Panel estimates of the effect of railway access on population with Conley standard errors

	Winners vs. runners-up	
	(1)	(2)
Panel A: Distance cut off 10 km		
Treatment effect	0.117***	0.136***
	(0.018)	(0.017)
Panel B: Distance cut off 20 km		
Treatment effect	0.117***	0.136***
	(0.020)	(0.019)
Panel C: Distance cut off 50 km		
Treatment effect	0.117***	0.136***
	(0.024)	(0.022)
Observations	3,276	3,276
Parish FE	Yes	Yes
Year × Case FE	No	Yes

Notes: The table shows panel regression estimates of the effect of railway access in 1845–54 on log population estimated for the winners versus runners-up sample. All regressions include a full set of year and parish dummies. Regression (2) additionally includes year-by-case fixed effects. Conley standard errors are in parentheses. We use Stata command `reg2hdfespatial` to calculate the Conley standard errors (Conley 1999; Hsiang 2010). The distance cut off is 10 kilometers in Panel A, 20 kilometers in Panel B, and 50 kilometers in Panel C. ***, **, and * denote statistical significance at the 1, 5, and 10 percent level, respectively.

Sources: Population data are from Statistisches Landesamt Baden-Württemberg (2008).

Table A-9: The effect of railway access on the gender wage gap

	Gender wage gap		
	1884	1898	1909
	(1)	(2)	(3)
Panel A: IPW			
Treatment effect	-2.007**	-1.736*	-0.698
	(1.020)	(0.940)	(0.576)
Panel B: IPWRA			
Treatment effect	-2.163**	-1.791*	-0.727
	(1.086)	(0.952)	(0.597)
Panel C: OLS			
Treatment effect	-2.146**	-1.918**	-0.672
	(1.032)	(0.944)	(0.552)
Observations	155	156	156
Control mean	32.78	32.85	33.94

Notes: The table shows regression estimates of the effect of railway access in 1845–54 on the gender wage gap of day laborers in 1884 (Column (1)), 1898 (Column (2)) and 1909 (Column (3)). The regressions in Panel A are estimated by IPW, regressions in Panel B by IPWRA and regressions in Panel C by OLS. All regressions include as control variables log population and log population density in 1834, the share of protestants in 1821, a dummy for having a manufactory in 1832, industry employment per 100 persons in 1829, elevation, dummies for access to a navigable river in 1845 and to a road in 1848, and case dummies. Robust standard errors are in parentheses. ***, **, and * denote statistical significance at the 1, 5, and 10 percent level, respectively.

Sources: The average daily wage of day laborers in 1884, 1898, and 1909 are from Königliches Statistisches Landesamt (1898) and Königliches Statistisches Landesamt (1910).

Appendix 19 Additional results for the full sample

Table A-10: Comparison of pre-treatment characteristics for parishes on and off straight-line corridors and least cost paths

	Full sample						
	Nodes	On least cost path (500 m)	Off least cost path (500 m)	Difference (2) - (3)	On straight line (500 m)	Off straight line (500 m)	Difference (5) - (6)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Pop. 1834 (log)	8.379	6.549	6.393	0.156	6.572	6.393	0.179
	(1.464)	(0.676)	(0.705)	[0.065]	(0.684)	(0.704)	[0.069]
Pop. density 1834 (log)	5.628	4.337	4.280	0.057	4.341	4.280	0.061
	(0.753)	(0.665)	(0.602)	[0.056]	(0.701)	(0.600)	[0.060]
Protestants 1821 (share)	0.730	0.561	0.621	-0.059	0.577	0.619	-0.042
	(0.379)	(0.491)	(0.468)	[0.044]	(0.485)	(0.469)	[0.046]
Manufactory dummy 1832	0.583	0.048	0.054	-0.006	0.073	0.052	0.020
	(0.515)	(0.215)	(0.226)	[0.021]	(0.261)	(0.223)	[0.022]
Ind. employment per 100 persons 1829	12.953	8.313	7.726	0.588	8.354	7.728	0.626
	(4.087)	(3.062)	(4.375)	[0.400]	(3.254)	(4.357)	[0.423]
Average elevation (in m)	391.685	416.112	499.072	-82.960	421.476	498.063	-76.587
	(120.070)	(140.525)	(155.773)	[14.394]	(136.118)	(156.252)	[15.253]
River dummy	0.417	0.161	0.071	0.090	0.155	0.073	0.082
	(0.515)	(0.369)	(0.258)	[0.025]	(0.363)	(0.260)	[0.026]
Road dummy	0.917	0.694	0.477	0.217	0.700	0.478	0.222
	(0.289)	(0.463)	(0.500)	[0.046]	(0.460)	(0.500)	[0.049]
Observations	12	124	1,722		110	1,736	

Notes: The table shows average values of pre-treatment characteristics for nodes (Column (1)), parishes that are (Column (2)) and are not (Column (3)) within 500 meters of a least cost path between the nodes, and parishes that are (Column (5)) and are not (Column (6)) within 500 meters of a straight-line between the nodes (Column (5)). Column (4) shows the mean difference in pre-treatment characteristic between parishes on and off the least cost path and Column (7) the mean difference between parishes on and off the straight-line corridor. Nodes are defined as parishes that are either starting or end points of a railway segment or serve as network junctions. In the calculation of the least cost path we follow Keller and Shiue (2016) and approximate the gradient related track costs by the foregone freight hauling capacity of trains. In addition, we incorporate political costs and penalize the crossing of foreign territory. We set the cost of crossing foreign territory to equal a complete loss of freight. We calculate a weighted sum of the different costs and create a cost raster, which is used in the least-cost path calculations using Esri ArcGIS's least cost path module. Standard deviations are in parentheses (Columns (1)–(3) and (5)–(6)). Standard errors of a two-sided mean difference t-test are in brackets (Columns (4) and (7)).

Sources: Population in 1834 is from Statistisches Landesamt Baden-Württemberg (2008). The share of Protestants is from Königliches Statistisches Landesamt (1824). The location of manufactories in 1832 is from Memminger (1833). Industrial employment 1829 is from various volumes of *Gewerbekataster* (Staatsarchiv Ludwigsburg E 258 VI). Elevation is from Bundesamt für Kartographie und Geodäsie (2017). The locations of rivers navigable in 1845 and paved roads in 1848 are from Kunz and Zipf (2008).

Table A-11: IV estimates of the effect of railway access on population

	Population			
	(1)	(2)	(3)	(4)
Second stage:				
Treatment effect	0.267***	0.178***	0.246***	0.153**
	(0.054)	(0.062)	(0.053)	(0.060)
First stage: Dependent variable – $Line_{ijt}$				
Least cost path (500 m) (0/1)	0.327***	0.283***		
	(0.041)	(0.043)		
Straight line (500 m) (0/1)			0.345***	0.291***
			(0.044)	(0.046)
Observations	38,766	38,766	38,766	38,766
Kleibergen-Paap F-statistic	64.384	42.766	61.430	40.462
Parish FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Year × County FE	No	Yes	No	Yes

Notes: The table shows IV regression estimates of the effect of railway access in 1845–54 on log population for the full sample. Regressions (1) and (2) use least cost paths and regressions (3) and (4) straight lines between railway nodes to instrument for railway access. All regressions include a full set of year and parish dummies. Regressions (2) and (4) additionally include year-by-county (*Oberamt*) fixed effects. Standard errors clustered at the parish level are in parentheses. ***, **, and * denote statistical significance at the 1, 5, and 10 percent level, respectively.

Sources: Population data are from Statistisches Landesamt Baden-Württemberg (2008).

Table A-12: The effect of railway access on day laborer wages, taxable income, and building values, full sample

	Day laborer wage (*Pfennig*)						Taxable income (*Mark*)	Building value (*Mark*)	Fire insurance value (*Mark*)
	Female			Male					
	1884	1898	1909	1884	1898	1909	1907	1907	1908
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel A: IPW									
Treatment effect	11.409***	13.586***	11.654***	8.488***	10.219***	16.899***	68.774***	1,364.0***	1,565.7***
	(1.917)	(1.989)	(2.212)	(2.183)	(2.393)	(3.899)	(12.169)	(248.9)	(317.5)
Panel B: IPWRA									
Treatment effect	11.456***	13.404***	11.593***	8.718***	10.271***	17.039***	69.810***	1,372.5***	1,584.4***
	(1.980)	(1.986)	(2.205)	(2.210)	(2.373)	(3.851)	(12.136)	(247.2)	(316.4)
Panel C: OLS									
Treatment effect	11.542***	12.876***	12.098***	9.377***	10.995***	18.829***	71.443***	1,435.691***	1,687.768***
	(1.931)	(1.985)	(2.201)	(2.126)	(2.387)	(3.826)	(12.508)	(253.712)	(314.626)
Observations	1,830	1,846	1,843	1,832	1,846	1,843	1,843	1,843	1,843
Control mean	106.53	116.21	165.76	159.34	173.01	246.96	320.96	2,763.9	3,794.0

Notes: The table shows regression estimates of the effect of railway access in 1845–54 on the average daily wage of female (Columns (1) to (3)) and male (Columns (4) to (6)) day laborers in 1884, 1898, and 1909, on taxable income per capita in 1907 (Column (7)), the average value of buildings in 1907 (Column (8)), and the average fire insurance value per building in 1908 (Column (9)). Values in Columns (1) to (6) are in *Pfennig* and values in Columns (7) to (9) are in *Mark*, with 1 *Mark* = 100 *Pfennig*. Regressions in Panel A are estimated by IPW, regressions in Panel B by IPWRA and regressions in Panel C by OLS. All regressions include as control variables log population and log population density in 1834, the share of protestants in 1821, a dummy for having a manufactory in 1832, industry employment per 100 persons in 1829, elevation, dummies for access to a navigable river in 1845 and to a road in 1848. Robust standard errors are in parentheses. ***, **, and * denote statistical significance at the 1, 5, and 10 percent level, respectively.

Sources: The average daily wage of day laborers in 1884, 1898, and 1909, taxable income and building value in 1907, and the fire insurance value of buildings in 1908 are from Königliches Statistisches Landesamt (1898) and Königliches Statistisches Landesamt (1910).

Table A-13: The effect of railway access on industrial development, full sample

	Emplyoment				Establishment size (logs)	Steam engine	
	Industry		Agriculture			(0/1)	HP pc
	1895	1907	1895	1907	1895	1869	1869
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A: IPW							
Treatment effect	4.771***	6.122***	-5.653***	-8.575***	0.382***	0.183***	9.12**
	(0.926)	(0.905)	(0.947)	(1.348)	(0.076)	(0.056)	(4.519)
Panel B: IPWRA							
Treatment effect	4.864***	6.208***	-5.785***	-8.787***	0.388***	0.186***	9.29**
	(0.939)	(0.927)	(0.975)	(1.322)	(0.076)	(0.056)	(4.516)
Observations	1,846	1,843	1,846	1,843	1,839	1,846	1,846
Panel C: Panel estimates							
Treatment effect	5.699***	6.738***	–	–	0.460***	0.263***	11.29**
	(0.901)	(0.827)			(0.082)	(0.060)	(4.484)
Observations	3,692	3,689			3,504	3,692	3,692
Control mean	9.629	11.06	31.50	36.84	0.478	0.073	1.002

Notes: The table shows estimates of the effect of railway access in 1845–54 on the number of full-time employees in industry (Columns (1) and (2)) and agriculture (Columns (3) and (4)) per 100 persons in 1895 and 1907, establishment size in industry in 1895 (Column (5)), the probability of having installed at least one steam engine by 1869 (Column (6)), and steam horsepower per 1,000 persons in 1869 (Column (7)). Establishment size is the average number of persons employed in a main plant (*Hauptbetrieb*). Panels A and B display IPW and IPWRA estimates, respectively. Regressions in Panels A and B include as control variables log population and log population density in 1834, the share of protestants in 1821, a dummy for having a manufactory in 1832, elevation, dummies for access to a navigable river in 1845 and to a road in 1848. Panel C displays estimates from panel fixed effects regression that include parish and year-by-county fixed effects. The pre-treatment period is 1829 in Columns (1) to (5) and 1846 in Columns (6) and (7). We cannot run panel fixed effects regression for agricultural employment, as we lack data on agricultural employment in the pre-treatment period. The control mean gives the mean value of the outcome for the control group in 1895 (Columns (1), (3), (5)) 1907 (Columns (2) and (4)) and 1869 (Columns (6) and (7)). Robust standard errors are in parentheses. Standard errors in Panel C are clustered at the parish level. ***, **, and * denote statistical significance at the 1, 5, and 10 percent level, respectively.

Sources: Employment data are from the occupation censuses of 1895 and 1907 (Königliches Statistisches Landesamt 1900a, 1910) and the *Gewerbestatistik* 1829 (various volumes of *Gewerbekataster*, Staatsarchiv Ludwigsburg E 258 VI) and 1895 (Königliches Statistisches Landesamt 1900b). Data on the location of steam engines are from archival records (Staatsarchiv Ludwigsburg E 170 Bü 272).

Table A-14: The effect of railway access on employment in key industrial sectors and specialization, full sample

	Employment in key industrial sectors					
		Coal, iron &	Machines & instruments			
	Textile	steel	all	electrical	Chem-ical	Spec-ialization
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: IPW						
Treatment effect	2.381***	-0.004	0.301*	0.007	0.076	0.005
	(1.069)	(0.056)	(0.171)	(0.008)	(0.088)	(0.014)
Panel B: IPWRA						
Treatment effect	2.398**	-0.003	0.303*	0.007	0.075	0.005
	(1.069)	(0.055)	(0.171)	(0.008)	(0.088)	(0.014)
Observations	1,846	1,846	1,846	1,846	1,846	1,839
Panel C: Panel estimates						
Treatment effect	3.352***	0.038	0.418**	0.008	0.098	0.031**
	(0.991)	(0.037)	(0.176)	(0.007)	(0.098)	(0.015)
Observations	3,692	3,692	3,692	3,692	3,692	3,504
Control mean	0.848	0.015	0.046	0.001	0.027	0.171

Notes: The table shows estimates of the effect of railway access in 1845–54 on the number of full-time employees per 100 persons in different industries (Columns (1)–(5)) and specialization within industry (Column (6)) in 1895. We distinguish between employment in the textile industry (Column (1)), coal, iron, and steel industry (Column (2)), building of machines and instruments (Column (3)), building of electrical machines and instruments (Column (4)), and the chemical industry (Column (5)). Specialization is measured by the Hirschman-Herfindahl-Index (with $\alpha = 2$). Panels A and B display IPW and IPWRA estimates, respectively, using employment in 1895 as outcome variable. Regressions in Panels A and B include as control variables log population and log population density in 1834, industry employment per 100 persons in 1829, a dummy for having a manufactory in 1832, the share of protestants in 1821, elevation, dummies for access to a navigable river in 1845 and to a road in 1848. Panel C displays estimates from panel fixed effects regression that include parish and year-by-county fixed effects. The pre-treatment period is 1829. The control mean gives the mean value of the outcome for the control group in 1895. Standard errors in Panel C are clustered at the parish level. ***, **, and * denote statistical significance at the 1, 5, and 10 percent level, respectively.

Sources: Employment data are from *Gewerbestatistik* of 1829 (various volumes of *Gewerbekataster*, Staatsarchiv Ludwigsburg E 258 VI) and 1895 (Königliches Statistisches Landesamt 1900b).

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