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Fast Track to Growth? Railway Access, Population Growth and Local Displacement in 19th Century Switzerland

Konstantin Büchel
Stephan Kyburz

THE LONDON SCHOOL OF ECONOMICS AND POLITICAL SCIENCE

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Abstract
We study the effect of railway access on population growth in 19th century Switzerland. Our analysis is based on geo-referenced railway network information and an inconsequential units IV approach. Gaining direct railway access increased annual population growth by 0.4 percentage points, while municipalities in close vicinity but no direct access (i.e. 2-10 km distance) experienced a growth slump of similar magnitude. We interpret these findings as evidence of highly localised displacement effects related to railway connections.

Key words: railway access, population growth, displacement effects
JEL: N33; N73; O18

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Konstantin Büchel, University of Bern, Department of Economics and Center for Regional Economic Development. Stephan Kyburz, Center for Global Development and 2017 visiting academic at Centre for Economic Performance London School of Economics.

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1 Introduction

The empirical evaluation of how transport infrastructure affects economic activity has recently attracted increased attention (see Redding and Turner, 2015). The rapid advance of railways is widely seen as a major driving force of economic development in the 19th century. It made overland transport at competitive rates possible, which facilitated the integration of formerly isolated areas into the regional and global economy. As this market widening enabled increased regional specialisation and gains from trade, it is argued that railway substantially fuelled aggregate economic growth.[1]

Economists have been concerned with two important questions regarding transport infrastructure and economic development. First, is regional growth accelerated by the construction of infrastructure or do major transport investments simply follow demand? And second, how is the spatial distribution of economic activity affected by transport infrastructure?

In this paper we provide new evidence on both questions exploiting the setup of Switzerland's railway expansion in the 19th century. Based on data for 2 800 municipalities, we conduct a spatially detailed analysis on how railway access impacted regional population growth. First, we address the potential cherry-picking of railway constructors by applying an inconsequential units IV approach as proposed by Banerjee, Duflo and Qian (2004; 2012). Based on cost estimates related to distance, gradients, and bridges, we simulate least-cost paths that serve as instrument for railway access. These instruments and various placebo tests allow us to cope with endogeneity issues related to the placement of railway lines. Second, we exploit the finely grained spatial data of Swiss municipalities to explore patterns of relocation related to railway infrastructure. As the median Swiss municipality has an area of only 7 km^2, we are able to investigate small-scale displacement effects not documented in other studies.

As regards the first question, Fishlow (1965) was one of the first economists who systematically analysed the direction of causation concerning railway construction and economic expansion. Based on his study of 19th century USA, he concludes that railway construction seems to have followed demand rather than cause regional population growth. Combining GIS-tools and econometric methods, Atack et al. (2010) revisit Fishlow's analysis for counties in the American Midwest from 1850 to 1860 and find that railway access increased population density by about 3 percentage points within the decade studied. More recent studies find that railways substantially accelerated urban growth, as documented for Prussia (Hornung, 2015), Sweden (Berger and Enflo, 2017), and Africa (Jedwabi and

[1] Based on the concept of social savings, first proposed by Fogel (1962, 1964), the impact of railway infrastructure on aggregate output has been calculated to range between 5% and 10% for the US, and between 1% and 11% for European countries (Leunig, 2010). In a recent study, Donaldson and Hornbeck (forthcoming) show that extensions to internal waterways and roads would have mitigated at most 20% of the losses from removing railways in the US, refuting the famous argument by Fogel (1964) that railways could have been easily substituted by other available means of transport.

Moradi, 2016).[2] We complement this literature by providing comprehensive evidence on the consequences of railway expansion in a mostly rural setup. The impact of railway access in Switzerland yields an average railway induced growth effect of 0.4 percentage points per year. This is of comparable magnitude to the impact of railway access that Atack et al. (2010) measure for US counties, but not even half the effect typically reported for cities.

There has been considerably less research on the second question, which concerns railway expansion and relocation of economic activity. Based on a multi-region theoretical framework, Redding and Turner (2015) discuss mechanisms that link changes in market access, trade flows, wages, land rents, and population growth. When some locations experience larger reductions in trade costs than others, labour relocates to these locations, until real wages are equalised across space. Fretz, Parchet and Robert-Nicoud (2017) further model skill heterogeneity among workers, and show that locations with improved market access become relatively more attractive to the high-skilled, high-income earners. This implies that transportation infrastructure not only affects population counts but also the composition of workers and residents.

Determining the distributional consequences of transportation infrastructure investments is fundamental, yet few empirical studies are spatially detailed enough to capture the potentially very localized displacement effects. Concerning highways, Chandra and Thompson (2000) show that they raise the level of economic activity in the counties that they pass directly through, but draw activity away from adjacent counties.[3] Concerning railways, Berger and Enflo (2017) show for a sample of 81 Swedish towns that the relative increases in population for connected locations came at the cost of their non-connected neighbours. Hence, they conclude that much of the growth attributed to the railways likely reflects a reorganization of economic activity. To the best of our knowledge, we provide so far the spatially most detailed evidence on reorganization of economic activity following a major railway expansion. Our municipal population growth data exhibits pronounced patterns of economic relocation: The positive effect of railway is highly localised, as municipalities situated more than 2 km from the railway network experienced a significant growth slump. The negative effect of railway peaks at a distance of 6 to 8 km from the railway tracks and reverses back to zero for places at least 10 km away.

The following section describes the historical setting. Section 3 introduces the data. Section 4 explains the empirical strategy. Section 5 discusses the results on railway access, population growth, and displacement effects. Section 6 concludes.

[2]Comparable questions were also studied for highway infrastructure built in the 20th century, for instance by Duranton and Turner (2012) or Faber (2014).

[3]There is also a large literature on suburbanisation due to the development of new city highways. Baum-Snow (2007) shows that population relocates to suburban areas as new highways are constructed through city centres. Baum-Snow et al. (2017) investigate how urban railways and highway configurations have influenced urban structures in Chinese cities since 1990. They show that radial highways decentralize service sector activity, radial railways decentralize industrial activity, and ring roads decentralize both. For the road network expansion in Switzerland, Fretz, Parchet and Robert-Nicoud (2017) find that municipalities incremented their population size by 11% in 20 years if a new highway was built within 10 km.

2 Historical Background

Although Switzerland was one of Europe's most industrialised countries in the early 19th century, railway technology caught up relatively late. Since 1836 entrepreneurs in Zurich sought to connect Switzerland's largest city to the foreign railway network at the German border in Koblenz and the French border in Basel, but since they failed to raise enough funds their endeavour stopped halfway in Baden. The first 23 km of railway tracks in Switzerland, which are known as "Spanisch-Brötli-Bahn", were opened in 1847, at a time when Great Britain (9 800 km), Germany (5 800 km), France (2 900 km), and the US (13 500 km) had already built several thousand kilometres of railway.[4]

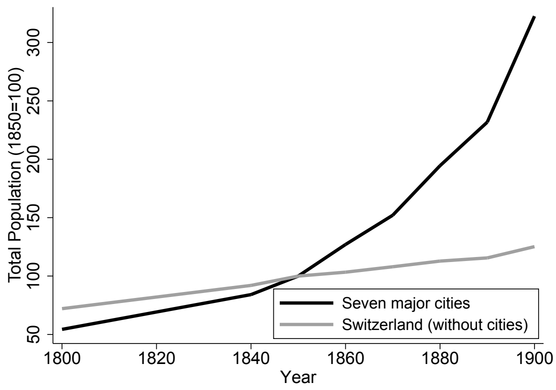
When the Swiss federal state was founded in 1848, the formation of a national railway network soon became one of the main priorities on the political agenda. Alfred Escher, president of the national council, warned his fellow members of parliament in 1849 that Switzerland would run the risk of becoming isolated within Europe if it failed to build a railway network quickly.[5] In 1850, the government commissioned two engineers, Robert Stephenson and Henry Swinburne, to provide a technical expertise for the construction of a national railway system. After fierce debates and a close vote, the plan submitted by the English engineers for a state-run railway network was rejected by the national assembly. The Railway Act of 1852 authorised cantonal administrations to grant concessions to private companies, which were supposed to build and run Switzerland's railway network without public funding (Weissenbach, 1913). This legal framework along with the introduction of a single currency and the elimination of internal tariffs in 1848 evidently reassured previously reluctant investors, and within a decade private railway companies connected Switzerland's major cities north of the Alps. By the end of the century Switzerland had one of the world's densest railway networks with a length of around 3 700 km.

Switzerland is a land-locked country with no navigable rivers except for the Rhine in the border town of Basel. Before railway became available, carts were the main means of transportation complemented by inland navigation on lakes.[6] It has been estimated that railway reduced land transport costs by a factor of eight (Donaldson, forthcoming), which stimulated two major developments in Switzerland: First, the agricultural sector started shifting production from grain to dairy products. While the production of milk increased by more than 70% until the end of the century, the production of grain decreased by 40%, a drop that was compensated by the quadrupling of grain imports (Frey and Vogel,

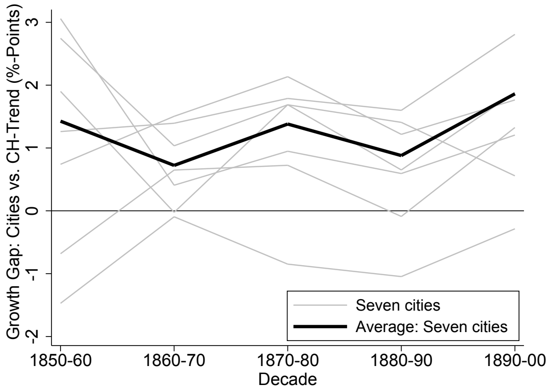
[4]Humair (2008) cites the fragmented system of tariffs, currencies and jurisdictions of the pre-modern Swiss confederation as key institutional barriers that inhibited adequate funding by (foreign) investors.

[5]Original quote from Alfred Escher's speech delivered in the national assembly on 12th November 1849 [Bundesblatt 1849, Vol. 3(6):161]: "Es tauchen Pläne auf, gemäss denen die [europäischen] Bahnen um die Schweiz herumgeführt werden sollen. Der Schweiz droht somit die Gefahr, gänzlich umgangen zu werden und in Folge dessen in der Zukunft das traurige Bild einer europäischen Einsiedelei darbieten zu müssen."

[6]Inland navigation was a regionally important – but *secondary* – complement to overland transport. Estimates by Frey (2010) reveal that the accessibility of Swiss municipalities in 1850 was almost entirely determined by roads (93%-100%), and hardly influenced by inland navigation (0%-7%). Transshipping costs were significant, which limited potential savings on the short portage routes on lakes (Schiedt, 2009).



(a) Population Development, 1800-1900 (Index: 1850=100).



(b) City Growth Rates p.A. versus National Average

Figure 1: Urbanisation and Railway in Switzerland. *Source:* Own calculations based on the *HSSO* database, `www.fsw.uzh.ch/histstat/`

Notes: The sample of cities includes Zurich, Geneva, Bern, Basel, Winterthur, Thun, and Biel. Cities were selected only if their population statistics for 1800 and 1837 reflect the territorial borders of the 1850–1900 sample. Graph (b) shows difference-in-difference annual growth rates: The differences between national and city growth rates from 1837 to 1850 were subtracted from the annual growth rate differences between 1850 to 1900 .

1997, chapter 8). Second, railway triggered large quantities of coal imports from Germany and France, which increased from 1 360 tons in 1851 to 16 000 tons ten years later, and more than 200 000 tons at the end of the century, representing 15% to 20% of the freight transported by rail between 1850 and 1900. Coal promoted an improved mechanisation of the Swiss industry, and cleared the way for energy-intensive sectors such as steel works, salterns, and cement production (Marek, 1991, chapter 6).

Besides lowering the transportation costs of cargo, railway substantially shortened travel-times. Frey (2006) illustrates on the basis of detailed stagecoach and train schedules that the time required to visit all cantonal capitals was halved between 1850 and 1870. By the end of the century, travel-times were even reduced by 80% compared to the pre-railway period. Despite these substantial improvements in accessibility, Frey and Schiedt (2005, 57) argue that railway contributed little to the public's mobility during the first 40 years, as it was unaffordable for the vast majority.[7] In 1880, Swiss railway companies only carried 25 million passengers, which corresponds to an average of nine train journeys per person per year. A gradual decline in fares during the 1890s and rising incomes made train travel more widespread, with yearly passenger numbers rapidly increasing to 63 million in 1900 and 110 million in 1910.[8] For most of the 19th century, however, rail journeys remained a privilege for the wealthy and commuting by train was rather insignificant.

The advent of railway took place in a period characterised by strong growth: Swiss GDP estimates available for the period after 1850 reveal that real output grew by approximately 250% within 50 years, while the population increased from 1 665 000 inhabitants in

[7]A look at fares and wages in the 1880s illustrates this point: An average worker, who earned about 0.30 CHF per hour, had to pay 0.90 to 1.40 CHF for a return-ticket on a 10 km railway route (NOB, 1883).

[8]Passenger statistics were obtained from the *Schweizerische Eisenbahnstatistik* (SPE, 1900), which is partly accessible online at `http://www.bahndaten.ch/` (last access: 01.02.2016).

1800 to 2 393 000 in 1850, and 3 315 000 by the end of the 19th century. This growth was not uniformly distributed across the country, however, as Switzerland witnessed substantial domestic migration typically from peripheral regions to the fast growing urban centres (e.g. Rey, 2003). The acceleration of urban growth in Switzerland coincides with the construction of the earliest railway lines. To illustrate this point, Figure 1 part (a) plots population statistics (1850=100) for a sample of seven cities with comparable population data for 1800 and 1836/37. While cities grew at a similar rate to other municipalities prior to railway construction (i.e. between 1800 and 1847), the picture changed completely in the second half of the 19th century. Urban population started increasing considerably while the rest of the country kept growing at a constant rate. Part (b) of Figure 1 presents a simple difference-in-differences analysis of the annual population growth rate of the seven cities compared to the national population growth rate using periods before and after the introduction of railway technology. Except for Thun, the growth rates of the cities increased by 0.5 to 3 percentage points relative to the national trend after the railway network was established. Of course this simple analysis cannot establish a causal relation, since early railway construction coincides with the birth of the modern federal state in 1848. Nonetheless, it reveals a suggestive pattern that fits well with recent findings on urbanisation and railway access in other countries (e.g. Hornung, 2015).

Although urban centres experienced rapid growth, Switzerland remained a rurally dominated country throughout the 19th century. In 1850, less than 10% of Switzerland's population lived in towns of more than 10 000 inhabitants, a ratio that remained decidedly below the 50% mark until the end of the century. In the following, we primarily analyse how demographic dynamics in Switzerland's rural areas were affected by railway access.

3 Data

We track the expansion of Switzerland's railway network using data from the "GIS Dufour" project, which developed a digitial map of historic roads, railway, and waterway lines based on the first national map commissioned by Henri Dufour in 1850 (source: Egli et al., 2005). In addition to mapping traffic routes, the GIS Dufour project also collected information on their opening and closing dates from various historical sources. Based on this rich data set, we define a binary indicator, referred to as *railway access*, that takes the value 1 if one or more railway lines cross over the territory of a municipality.[9] Accordingly, we call municipalities "treated" after they received their first railway access, and "untreated" if no railway line passed through.[10] The last two columns of Table 1 show the percentage

[9]We use municipal boundaries from official administrative maps of Switzerland valid from January 2000. This ensures that the spatial administrative division used to determine a municipality's railway access is congruent with the classification employed in the census data.

[10]We deliberately measure railway access based on railway lines instead of railway stations, as the use of stations would exacerbate endogeneity concerns. Yet, we show in an number of robustness checks that the qualitative insights of our main analysis do not depend on this choice (see section 5.2 as well as the results in appendix B.2.3, and B.2.6).

Table 1: Descriptive Statistics: Population and Railway Access in Swiss Municipalities

	Swiss Pop. (in mio.)	Municipalities: Average Population		Rail Access: %-Share of	
		All	With Rail Access	Munipalities	Population
1850	2.39	840	8603	0.3	3.2
1860	2.51	877	2049	12.9	30.0
1870	2.66	927	2006	17.4	37.5
1880	2.83	986	1817	29.3	53.9
1890	2.92	1013	1797	35.1	62.4
1900	3.32	1150	2067	39.0	70.3

Source: Own calculations based on Swiss census data and GIS-Dufour data.

share of municipalities and residents that were connected to the railway network.

We further aim to precisely measure the distance of municipalities to the closest railway line. The Dufour Map's first edition (published around 1860) serves as our main source to identify municipal cores: We project administrative boundaries on the Dufour Map, and mark all churches explicitly designated by a distinct symbol; the underlying idea is that churches are a good proxy for the historically established municipal centre. If a municipality has several churches and settlements, we mark the church located within the major village. For a small number of municipalities no churches were designated in the Dufour Map. For these cases, we visually identify the settlement's core. Having marked all municipality centres, the euclidean distance to the closest railway line is computed with ArcGIS, and used as main explanatory variable in section 5.3.

Our main outcome of interest is annual population growth. Population statistics are taken from the census ("Eidgenössische Volkszählung") which has been conducted by the Swiss Statistical Office (and its precursor) since 1850. The national census has always surveyed the population on the municipality level in intervals of 10 years, with the exception of the 1890-wave, which was collected in 1888. We infer the population for 1890 by performing an extrapolation of growth rates in the adjacent periods, i.e. 1880 to 1888 and 1888 to 1900, respectively.[11] In order to account for territorial reorganisations, we use the municipality classification for 2000 and clean population figures based on the data set's documentation on territorial mergers and divisions. For the cantons of Zurich, Bern, Aargau and Solothurn, we complement the census data with population statistics from the "Helvetische Zählung" conducted around 1800 and the "Tagsatzung" in 1837. These early population counts are currently being harmonised with the post-1850 census data in an ongoing project by Schuler and Schluchter (in progress). In what follows, we refer to this subset of municipalities, representing around 900 of the 2800 municipalities, as the *pre-railway sample* or *pre-treatment sample* (see Figure 3). We construct our main dependent variable, the annual population growth rate for each municipality based on the population figures for 1800, 1837, and 1850 to 1900.[12]

[11] Mathematically, we calculated the population count (POP_{90}) of 1890 as follows: $PGR_{80,88} = (\frac{POP_{88}}{POP_{80}})^{1/8}$; $PGR_{88,00} = (\frac{POP_{00}}{POP_{88}})^{1/12}$; $POP_{90} = \frac{1}{2}POP_{88} \cdot (PGR_{80,88})^2 + \frac{1}{2}POP_{88} \cdot (PGR_{88,00})^2$.

[12] Annual population growth is computed as follows: $APG^t = 100 \cdot (ln(POP_{t1}) - ln(POP_{t0}))/(t_1 - t_0)$.

A concern may be that population changes caused by railway-related *construction work* is falsely attributed to improvements in a municipality's or district's accessibility. In order to address such concerns, we resort to Rey (2003, 147–149) who compiled a list of Swiss municipalities and districts that experienced extraordinary demographic volatility due to railway construction work (mainly tunnelling). These observations are removed from our sample in all steps of the analysis that evaluate the affected time period.

4 Empirical Strategy: Instrumental Variable Approach

Railway access is not randomly assigned to municipalities, but may be correlated with numerous observable and unobservable characteristics such as population size, growth potential, economic structure, or the availability of cheap land. Since Switzerland's main railway infrastructure was built and run by private entrepreneurs until 1902, concerns related to targeted and selective routing cannot be ignored. Although a number of control variables are available, cross-sectional OLS regression may not be sufficient to account for these endogeneity issues. A priori, it is unclear whether an upward or downward bias dominates, thus making it difficult to interpret plain regression estimates.

We address these concerns by adopting an *inconsequential units IV approach* first proposed by Banerjee, Duflo and Qian (2004; 2012) and later used in several studies on transport infrastructure. The underlying idea is compelling: In the early stages of transport infrastructure developments, major cities – hereinafter "main nodes" – are typically connected first. If railway companies built their routes such that two main nodes are connected as directly as possible, railway access would be randomly assigned to municipalities lying along these inter-node connections. It is likely, however, that railway companies deliberately take detours, for instance to connect municipalities with a high growth potential or to avoid expensive land acquisitions in dense areas. As these targeted detours induce selection effects, it is not sufficient to restrict the analysis to inter-node lines as they were actually built. Instrumental variables based on straight line corridors or least-cost paths between nodes solve this issue. The IV approach bases inference on the randomly chosen subset of municipalities that received railway access because they lie on the most direct route between nodes. Our IV approach rests on least-cost paths instead of straight line corridors, as Switzerland's mountainous terrain and numerous lakes entail too low first stage correlations when the latter is used.

4.1 Main Nodes

Main nodes are selected along two dimensions in this study, namely economic and transport strategic importance. As a first group, we chose the 20 most populous municipalities in 1850 that held the historical town status (source: Guyer, 1960). In medieval times, towns privileges included judicial liberties, coinage, the right to collect tariffs, and the right to hold markets, which we consider a good proxy for historically grown economic importance. These 20 nodes are supplemented by 23 locations listed as central traffic junctions in plans delivered to the federal government by Robert Stephenson and Henry Swinburne in 1850. Since 10 municipalities are included in both sets, this yields 33 main nodes, that we believe were of primary economic or transport strategic importance, thus making them attractive to railway companies (see Table A.3 in the appendix). These 33 municipalities are excluded from the sample in all steps of the statistical analysis, as they have gained access to the railway for reasons potentially endogenous to population growth.

4.2 Least-Cost Paths

Whether or not a least-cost path is drawn between two nodes is determined based on records of actual railway openings (source: Wägli, 1998; Weissenbach, 1913). Lines are selected only if the primary intention of the railway company was to connect two nodes, excluding routes that established inter-node connections gradually over long periods of time. For the selected inter-node lines, we draw cost efficient routes on a 200 m x 200 m grid with the ArcGIS-tool "Least Cost Path" factoring in three cost parameters: distance, slope, and river crossings. In order to estimate the cost parameters, we extract information from the Swiss Traffic Atlas (source: NOB, 1883) on the total construction costs of 48 railway lines built by 1881, and combine it with information on mileage as well as slopes covered by the actual route of the tracks using a 25 m x 25 m height model for Switzerland (source: Swisstopo, 2004). A regression of total construction costs per kilometre on the routes' average slope yields estimated construction costs of 180 000 CHF per kilometre and an additional 15 000 CHF penalty per degree climbed. The costs of building bridges are determined based on the regression's residual for a 2 km track section that includes a 216 m long bridge over the river Rhine in Basel. We obtain costs of 800 000 CHF for the rail bridge in Basel, which we linearly scale down for smaller rivers based on federal water quantity statistics (source: Pfaundler and Schönenberger, 2013).

This procedure, which is described at full length in the appendix (see section A.2), yields a least-cost path for every inter-node railway connection built in 19th century Switzerland, including information on the original route's opening date. Finally, we intersect the least-cost paths with municipal boundaries, giving us an indicator, LCP^w, coded 1 if a municipality is traversed by a least-cost path during the construction wave w, and coded 0 if all the least-cost paths bypass outside the municipality in the given period.

We assess the sensitivity of our main results by simulating least-cost paths for different parameter values. As Tables A.4 and B.2 in the appendix show, the LCP-classification of municipalities and results prove very robust to varying the bridge cost parameter between 600'000 CHF and 1'000'0000 CHF, as well as to altering the slope penalty between 9'200 CHF ($\approx$ 15'000 CHF $-$ 1 s.e. in the cost regression) and 20'800 CHF ($\approx$ 15'000 CHF $+$ 1 s.e. in the cost regression).

4.3 Estimation and Identifying Assumptions

The data and instrumental variable, LCP_{ic}^{w}, described in the previous sections are used to estimate the effects of railway access, RA_{ic}^{w}, established during construction wave w, on annual population growth, APG_{ic}^{t}, in municipality i of canton c during decade t. The first and second stage regressions take the form

$$RA_{ic}^{w} = \alpha_1 + \beta_1 LCP_{ic}^{w} + \varphi_1 X_{ic}^{1850} + \kappa_{1c} + \epsilon_{ic}, \text{ and} \tag{1}$$

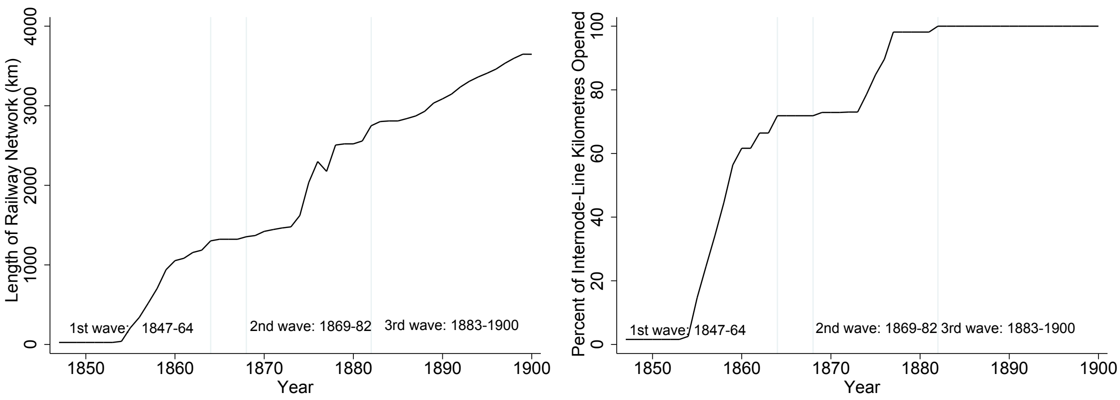
$$APG_{ic}^{t} = \alpha_2 + \beta_2 \widehat{RA}_{ic}^{w} + \varphi_2 X_{ic}^{1850} + \kappa_{2c} + \eta_{ic} \tag{2}$$

where κ_c denotes cantonal fixed effects, and X_{ic}^{1850} is a vector of municipality control variables described below.

A word on timing. The cross-sectional analysis exploits the fact that the construction of Switzerland's railway was carried out in three waves (see Figure 2): Between 1847 and 1864 the main trunk lines were established, including the east-west connection linking Geneva (westernmost city), Bern (capital), Zurich (largest city), and St. Gallen (easternmost city). During the second wave, 1869 to 1882, further inter-city lines were completed and the first north-south route through the Alps was opened. After 1882, the ramification advanced and mostly small branch lines were added. The focus of the analysis lies on the first wave, i.e. w=1847–1864, and the second wave, i.e. w=1869–1882. Equations (1) and (2) are estimated separately for both waves, and five decades of annual population growth available, i.e. t=1850–60; 1860–70; 1880–90; 1890–1900. When the second wave of railway constructions is analysed, all municipalities with access prior to 1869 are excluded from the sample.

Two assumptions are needed in order to allow for a causal interpretation of $\hat{\beta}_2$: First, the instrumental variable and the treatment have to be correlated (i.e. $\beta_1 \neq 0$), which can be tested formally based on the first stage correlation. Second, the exclusion restriction must hold, implying that the instrument needs to be as good as randomly assigned conditional on control variables, and may affect the outcome only through the first stage (e.g. Angrist and Pischke, 2009, 117). While our large and highly statistically significant estimates for β_1 verify the first assumption, the exclusion restriction could be violated if locations along the least-cost path are correlated with municipality characteristics due to history or geography. In order to justify the exclusion restrictions, we include a number of control variables, which are briefly motivated hereafter (further information on the controls are presented in the Appendix, A.1).

By construction, municipalities nearby nodes are more likely to lie on a least-cost path than municipalities farther away. If proximity to a city or major traffic junction is correlated with population growth, the exclusion restriction would be violated. We therefore include the *log distances* of each municipality to its closest *town node* and to its



(a) Length of Swiss Railway Network

(b) Share of Inter-Node Tracks Operating

Figure 2: Construction of the Swiss Railway Network: 1st Wave 1847–64, 2nd Wave 1869–82, 3rd Wave 1883–1900. *Source:* Own calculations based on GIS-Dufour data

closest *Stephenson-Swinburne node* as controls in our regressions.

The least-cost paths reflect direct routes between main nodes that avoid steep slopes and unnecessary river crossings. Location along these paths could be correlated with the economic structure of municipalities since they potentially coincide with historical trade routes that affected business prior to adoption of the railway technology. To account for this issue, we include a *road access* variable that measures whether a municipality is passed through by a major inter-cantonal road (source: GIS-Dufour, Egli et al., 2005). Before railway became available, these paved roads constituted the main inter-regional transport routes within Switzerland, and therefore should pick up possible confounding effects due to the potential correlation between historical trade routes and our instrument. Additionally, we include an indicator for *medieval town privileges* (source: Guyer, 1960), which were – amongst others – given to municipalities of trade strategic importance, and therefore may be correlated with both the likelihood of a municipality being crossed by a least-cost path and its population growth.

Naturally, our least-cost path algorithm tends to favour riversides, lake fronts, and low altitudes, as such terrain is often characterized by low gradients. A concern could be, that these places are also advantageous to economic development: Water turbines along rivers, for instance, were an important energy source in 19th century Switzerland, shipping on lakes was a regionally important complement to overland transport, while low altitudes pose favourable climatic conditions compared to higher elevations. Therefore, we include measures for *hydro power potential*, *adjacency to lakes*, and the *log of elevation* in our regressions.

A last set of controls is supposed to account for growth effects of *subsequent railway access*, and pre-determined population dynamics, namely *annual population growth prior to railway access*, the *log of population size in 1850*, as well as a municipality's *log area* in square kilometres.

Despite this broad set of control variables, it may still be possible that unobserved characteristics are correlated with both our instrument and the growth potential of municipalities, which would confound our estimate of β_2. We therefore complement our cross-sectional analysis with panel-models that take care of time-invariant unobserved heterogeneity by including municipality fixed effects, α_i. We regress the annual population growth rate of municipality i in decade t, APG_{ict}, on the instrumented dummy variable indicating railway access in the previous decade, RA_{ict-1}. The first and second stage IV panel-regressions are specified as

$$RA_{ict} = \alpha_{3i} + \beta_3 LCP_{ict} + \lambda_{3t} + \lambda_{3t} \cdot \kappa_{3c} + \xi_{ict}, \text{ and} \tag{3}$$

$$APG_{ict} = \alpha_{4i} + \beta_4 \widehat{RA}_{ict-1} + \lambda_{4t} + \lambda_{4t} \cdot \kappa_{4c} + \varepsilon_{ict} \tag{4}$$

where time fixed effects, λ_t, control for population growth cycles on the national level, and cantonal-time fixed effects, $\lambda_t \cdot \kappa_c$, account for cycles on the regional level.[13]

Since the Swiss census was conducted with a periodicity of ten years, the timing of treatment and effect is rather imprecise in our setting. To eliminate concerns of reverse causality and because main lines were mostly built in the second half of the 1850s and 1870s, we use the first lag of railway access in our preferred panel specification, e.g. railway access between 1851 and 1860 affects population growth during the decade 1860 to 1870 and onwards.

5 Results on Railway Access and Population Growth

Suggestive evidence for the impact of railway access on population growth is presented in Table 2, which compares the mean population growth rates for municipalities gaining railway access during the earliest wave of railway construction (1847–1864) to the growth rates of municipalities bypassed by these railway lines. While a two-sided T-test of differences in means (see column 4) suggests that population growth rates were not statistically different in the two groups during the pre-railway period, growth rates significantly diverged with the construction of the earliest railway lines during the 1850s and subsequent decades. Overall, this simple comparison in means suggest that municipalities with railway access grew on average 0.25 to 0.55 percentage points faster per year than unconnected municipalities.

In order to identify the causal impact of railway access on population growth rates, we now turn to our econometric analysis which is discussed in three subsections. First, we present results from a cross-sectional analysis. We complement the cross-sectional results in a second step with panel data regressions. Finally, we attempt to gain insights into

[13] Map A.1 in the appendix depicts the time-variation in our instrument.

Table 2: Annual Population Growth Rates by Railway Access Status in 1864

	Pre-Railway Sample[a]				Whole Switzerland[a]			
		Rail	No Rail			Rail	No Rail	
	Obs.	Mean	Mean	*Difference*	Obs.	Mean	Mean	*Difference*
	(1)	(2)	(3)	*(4)*	(5)	(6)	(7)	*(8)*
1800–1837	903	0.89	0.92	*−0.03*				
		(0.49)	(0.48)	(0.04)				
1837–1850	903	0.60	0.66	*−0.07*				
		(0.71)	(0.89)	(0.08)				
1850–1860	903	0.13	−0.017	*0.30***	2811	0.57	0.02	*0.55****
		(0.87)	(1.06)	(0.09)		(1.26)	(1.14)	(0.06)
1860–1870	903	0.59	0.20	*0.39****	2827	0.47	0.22	*0.25****
		(0.88)	(1.26)	(0.09)		(1.25)	(1.04)	(0.06)
1870–1880	898	0.46	−0.06	*0.52****	2788	0.45	−0.02	*0.47****
		(0.96)	(1.03)	(0.09)		(1.11)	(1.09)	(0.06)

Notes: Columns (4) and (8) present a two-sided T-test of the difference in means of municipalities with railway access to those without railway access. ***a:*** Sample excludes nodes and municipalities affected by railway construction work. Standard deviations in parentheses in columns (2), (3), (6), and (7). Standard errors in parentheses in columns (4) and (8). + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

regional displacement effects of railway access and effect heterogeneity.

5.1 Cross-Sectional Analysis

The cross-sectional analysis focusing on railway lines constructed between 1847 and 1864 is presented first, followed by a discussion on the second wave of railway development that lasted from 1869 to 1882. Our benchmark results are based on a sample including all the municipalities of Switzerland, except for the 33 main transport nodes and municipalities that experienced extraordinary demographic volatility due to railway construction work.

Table 3 presents the findings for the *first wave* of railway expansion (1847–1864), illustrated in Figure 3. The first column reports results for a placebo test based on the pre-railway period between 1800 and 1850. Both the OLS and IV coefficients for the pretreatment period are close to zero and statistically insignificant. This indicates that conditional on our control variables, population growth rates in treated and untreated municipalities were similar previous to the railway era. This changed following the construction of the railway network. Column (2) captures the effects of railway lines on long-term population growth between 1850 and 1900. Municipalities that were connected to the railway network between 1847 and 1864 experienced a significant increase in population growth during the second half of the 19th century.

The IV estimates, shown in the middle panel of Table 3, imply an additional annual growth of 0.39 percentage points, which translates into a relative population increase of over 20% within 50 years. An average municipality with early railway access and 750 inhabitants in 1850 would therefore have gained around 160 additional inhabitants by 1900 compared to an identical municipality without railway access.

Looking at every decade individually, our IV estimates in columns (4) to (7) imply that municipalities with railway access experienced additional annual growth of 0.31 to 0.58

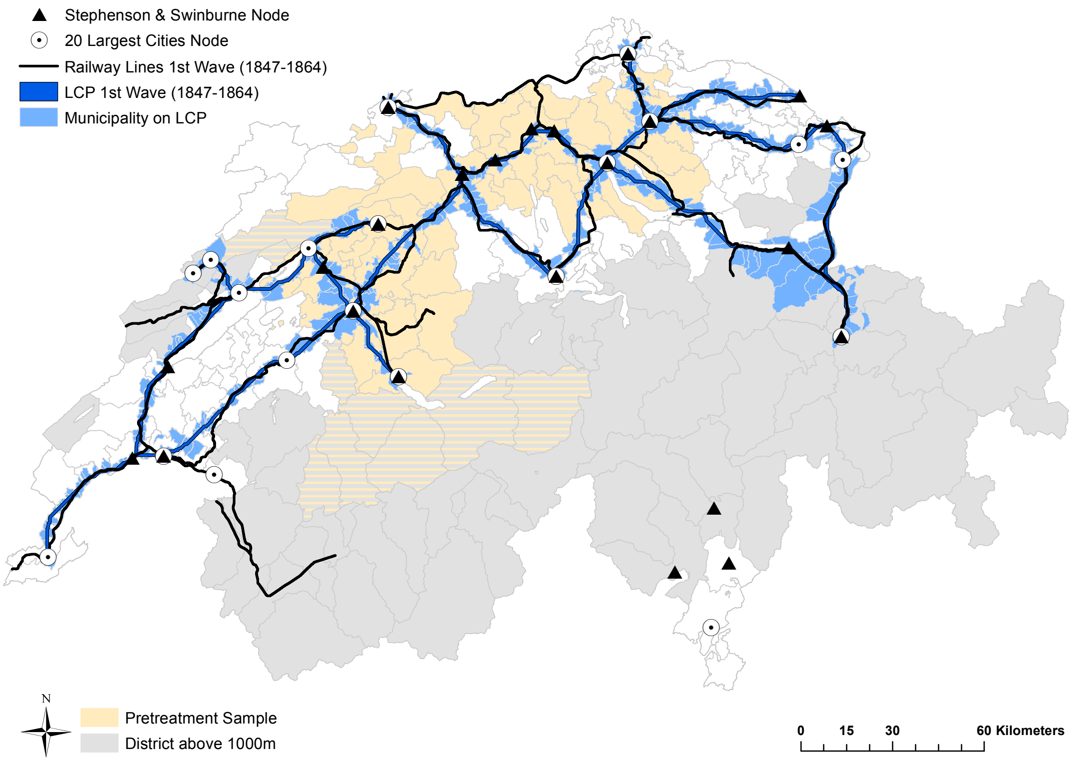


Figure 3: Railway Lines and Least-Cost Paths, 1^{st} Wave

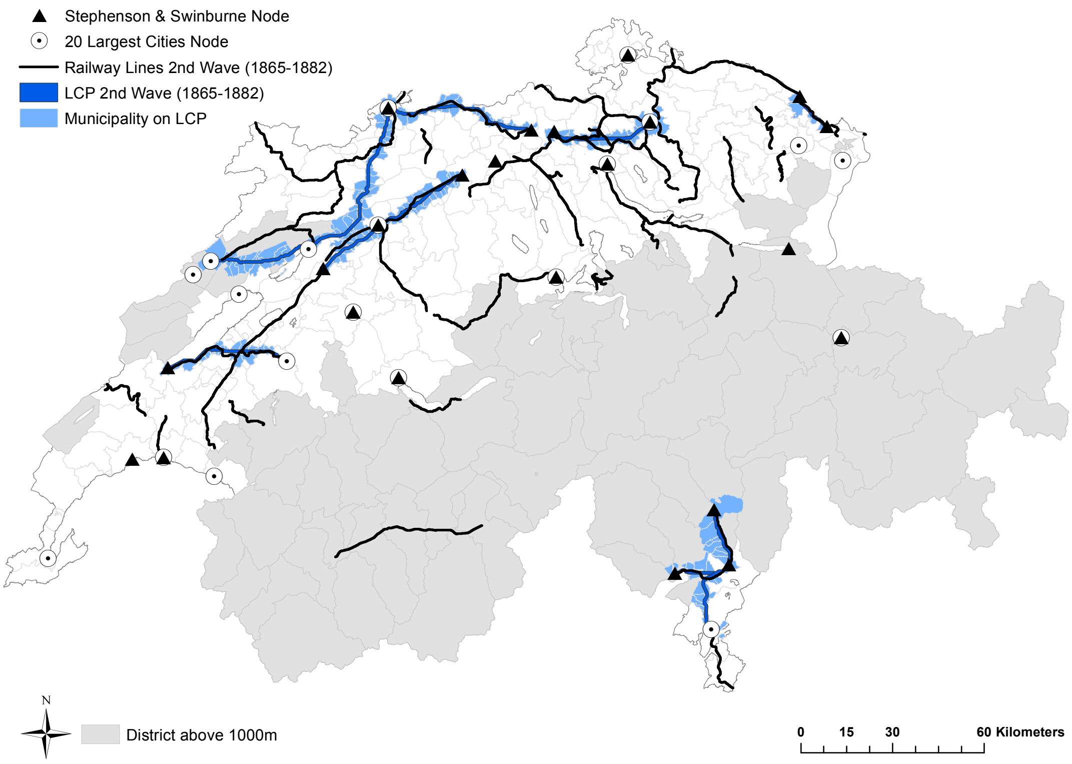


Figure 4: Railway Lines and Least-Cost Paths, 2^{nd} Wave

Table 3: The Impact of Railway Access (1847–64) on Annual Population Growth Rates, Cross-Sectional Estimates at the Municipal Level

	Long Run		10 Year Periods				
	1800–50[a]	1850–1900	1850–60	1860–70	1870–80	1880–90	1890–1900
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
OLS: Annual Population Growth Rates and Railway Access							
Rail Access 1847–64	0.00	0.41^{***}	0.31^{***}	0.26^{***}	0.36^{***}	0.34^{***}	0.56^{***}
	(0.04)	(0.04)	(0.06)	(0.07)	(0.06)	(0.06)	(0.08)
R^2	0.26	0.28	0.17	0.07	0.11	0.11	0.12
Observations	903	2770	2791	2790	2748	2743	2769
IV, Second Stage: Annual Population Growth Rates and Railway Access							
Rail Access 1847–64	0.15	0.39^{***}	–0.06	0.31^{*}	0.58^{**}	0.32^{+}	0.47^{*}
	(0.15)	(0.10)	(0.15)	(0.15)	(0.18)	(0.18)	(0.22)
Observations	903	2770	2791	2790	2748	2743	2769
IV, First Stage: Actual Railway Access 1847–64 and Least-Cost Paths							
LCP 1847–64	0.25^{***}	0.33^{***}	0.41^{***}	0.40^{***}	0.35^{***}	0.34^{***}	0.33^{***}
	(0.04)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
R^2	0.29	0.39	0.33	0.33	0.37	0.37	0.39
Observations	903	2770	2791	2790	2748	2743	2769

Notes: The dependent variable is annual population growth in percent. The controls used are distance to the nearest town node, distance to the nearest Stephenson-Swinburne node, subsequent railway access, access to main road, access to navigable water, elevation, water power potential, town privilege, population in 1850, area in km^2, annual district population growth 1800–1850, and cantonal fixed effects. ***Sample:*** All municipalities of Switzerland, excluding nodes and municipalities affected by railway construction. ***a*:** Pre-railway sample available for four cantons (ZH, BE, SO, AG). The instrument is based on a least-cost path for railway lines between the 20 largest cities and Stephenson-Swinburne nodes. Huber-White standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

Table 4: The Impact of Railway Access (1869–82) on Annual Population Growth Rates, Cross-Sectional Estimates at the Municipal Level

	Long Run		10 Year Periods				
	1850–70[a]	1870–1900	1850–60[a]	1860–70	1870–80	1880–90	1890–1900
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
OLS: Annual Population Growth Rates and Railway Access							
Rail Access 1869–82	0.24^{***}	0.36^{***}	0.24^{***}	0.19^{**}	0.32^{***}	0.23^{***}	0.42^{***}
	(0.05)	(0.04)	(0.07)	(0.06)	(0.06)	(0.07)	(0.08)
R^2	0.15	0.22	0.15	0.07	0.09	0.11	0.11
Observations	2344	2344	2365	2364	2324	2320	2344
IV, Second Stage: Annual Population Growth Rates and Railway Access							
Rail Access 1869–82	–0.08	0.51^{**}	0.01	–0.19	0.37	0.60^{*}	0.49
	(0.19)	(0.18)	(0.27)	(0.23)	(0.29)	(0.26)	(0.35)
Observations	2344	2344	2365	2364	2324	2320	2344
IV, First Stage: Actual Railway Access 1869–82 and Least-Cost Paths							
LCP 1869–82	0.36^{***}	0.36^{***}	0.37^{***}	0.37^{***}	0.35^{***}	0.36^{***}	0.36^{***}
	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)
R^2	0.32	0.32	0.29	0.29	0.27	0.28	0.32
Observations	2344	2344	2365	2364	2324	2320	2344

Notes: The dependent variable is annual population growth in percent. The controls used are distance to the nearest town node, distance to the nearest Stephenson-Swinburne node, subsequent railway access, access to main road, access to navigable water, elevation, water power potential, town privilege, population in 1850, area in km^2, cantonal fixed effects, and population growth 1850–1860 (except for columns ***a***, where district population growth 1800–1850 is used). ***Sample:*** All municipalities, excluding nodes and municipalities affected by railway construction work. The instrument is based on a least-cost path for railway lines between the 20 largest cities and Stephenson-Swinburne nodes. Huber-White standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

percentage points compared to municipalities without a railway connection. This effect is significant at the 10% level or higher, except for the first decade of railway construction from 1850 to 1860 suggesting that railway access impacted population growth with a time lag. The OLS and IV coefficients are similar in magnitude, which substantiates the claim that early railway companies prioritised direct connections between large cities, and did not necessarily target fast growing municipalities along the way. Note that the first stage, which is presented in the table's bottom panel, yields a strong and highly significant correlation between the instrument and the railway access variable. This alleviates concerns related to weak instruments.[14]

The results for the *second wave* of railway construction (1869–1882), which expanded the network by another 1 500 km of tracks, are presented in Table 4. Municipalities that gained railway access by 1864 were excluded from these regressions. Again, the first stage results for the IV models yield large and highly significant correlations between our instrument and railway access.

Columns (1), (3), and (4) display placebo tests based on an analysis of population growth rates from 1850 to 1870 and railway access obtained between 1869 and 1882. The OLS regressions produce a positive and statistically significant correlation, indicating that municipalities with a higher population growth rate in this pre-treatment period were more likely to receive railway access between 1869 to 1882. The IV approach mitigates this issue, with coefficients being close to zero or negative and statistically insignificant in both the short (1850–60; 1860–70) and long run perspective (1850–70).

While pre-treatment annual growth rates are not correlated with the instrumented railway access indicator, we obtain strong correlations for the post-treatment period. Estimates for the long run effect spanning 30 years from 1870 to 1900 are displayed in the second column and show a positive and highly significant effect of railway access on population growth, with the IV estimate amounting to 0.51. Columns (5) to (7) report the analogous results for each decade separately, which display positive effects of railway access across all specifications, while in two cases the coefficients are insignificant with t-values between 1.3 and 1.4. The effects of railway access on population growth rates vary between 0.37 and 0.6 percentage points. As for the results on the first wave of railway expansion, the post-treatment IV estimates are not statistically different from the OLS estimates in this second set of cross-sectional regressions.

The control variables enter with the expected sign and are mostly significantly different from zero. Table B.1 in the appendix reports the controls' coefficients for the long run regression that models population growth between 1850 and 1900. In particular, road access, the potential to produce hydro energy, subsequent railway access, larger surface

[14] When instrumenting the first wave of railway lines, 378 municipalities are crossed by a least-cost path, i.e. $LCP^{1864} = 1$. In this group, 241 municipalities (i.e. "compliers") received railway access until 1864, while 137 municipalities (i.e. "never-takers") did not. Among the 2 509 municipalities with $LCP^{1864} = 0$, 2249 (i.e. "compliers") did not receive railway access, while 260 (i.e. "always takers") were crossed by a railway line.

area, and town privileges are associated with higher population growth, while it decreases with distance to city nodes and higher elevation.

5.2 Panel Data Analysis and Robustness

The cross-section estimations include various control variables that account for municipality specific characteristics. Nevertheless, unobserved characteristics may still influence the particular growth potential of a municipality. The fixed effect estimation allows us to base inference on within municipality variation, which eliminates biases from time-invariant unobserved characteristics. Table 5 presents our preferred panel estimations that use the lag of railway access as main explanatory variable.

Table 5: The Impact of Railway Access on Annual Population Growth Rates, Panel Estimates at the Municipal Level

	Whole Switzerland[a]		Below 1 000 m[b]		Pre-Treatment Sample[c]	
	OLS FE	IV FE	OLS FE	IV FE	OLS FE	IV FE
	(1)	(2)	(3)	(4)	(5)	(6)
Annual Population Growth Rates in Decade t and Railway Access in Decade $t-1$						
Lag Railway Access	0.08*	0.42**	0.13**	0.41**	0.29***	0.44*
	(0.04)	(0.13)	(0.04)	(0.13)	(0.06)	(0.18)
R^2	0.05	–	0.05	–	0.17	–
Municipalities	2731	2731	2020	2020	821	821
Observations	13651	13651	10100	10100	4926	4926
Municpality FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Canton Time FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: The dependent variable is annual population growth rate in percent. Full sample, ***a:*** All municipalities of Switzerland, excluding nodes and municipalities affected by railway construction work. Below 1 000 m sample, ***b:*** All municipalities of districts with mean elevation below 1 000 m.a.s.l., excluding nodes and municipalities affected by railway construction work. ***c:*** This estimation additionally includes the pre-treatment period 1837–1850, but is restricted to a smaller sample of municipalities for which pre-railway population data is available (four cantons: ZH, BE, SO, AG), excluding nodes and municipalities affected by railway construction work. The instrument is based on a least-cost path for railway lines between the 20 largest cities and Stephenson-Swinburne nodes. Huber-White standard errors in parentheses. + $p<0.10$, * $p<0.05$, ** $p<0.01$ *** $p<0.001$.

We provide results for OLS and IV fixed effects estimations for three different samples. The first sample includes all the municipalities in Switzerland (see column 1 & 2). The second sample excludes municipalities where the mean district elevation is higher than 1 000 m.a.s.l. in order to remove the barren alpine region (see column 2 & 3). The third sample is restricted to municipalities for which pre-railway population data is available, so that the decade from 1840 to 1850 can be included in the estimation as well (see column 3 & 4). For all samples the main nodes and municipalities affected by railway construction work are excluded.

The IV coefficients in columns (2), (4) and (6) range between 0.41 to 0.44 for all three samples and are statistically significant at the 5% level or higher. Remarkably, they are also very close to the long run effects estimated in the cross section (first wave: 0.39, second wave: 0.51). Although this effect is less than half of the estimates reported for cities (see Hornung, 2015; Berger and Enflo, 2017), it is not negligible. A coefficient of 0.42 translates into an additional population count of 23% after 50 years for municipalities that got connected to the railway infrastructure compared to municipalities without railway access.

In Section B.2 of the appendix, several tables address the sensitivity of our panel and cross-section results along a number of dimensions. The results prove very stable, when using different parametrizations of the least-cost paths (see Table B.2), and when restricting the sample to municipalities in the cantons Zurich, Bern, Aargau, and Solothurn, where pre-railway population data is available (see Table B.3). As one would expect, the IV point estimates get systematically larger when substituting our railway access indicator with a railway station indicator: instead of 0.34 (wave 1) / 0.51 (wave 2) / 0.39 (panel IV) percentage points additional annual growth, we obtain 0.60 / 0.91 / 0.66 percentage points additional annual growth for municipalities with railway stations (see Table B.4); since the decision to operate a railway station on an existing railway line was probably endogenous to population dynamics, we consider the railway access measure more insightful.

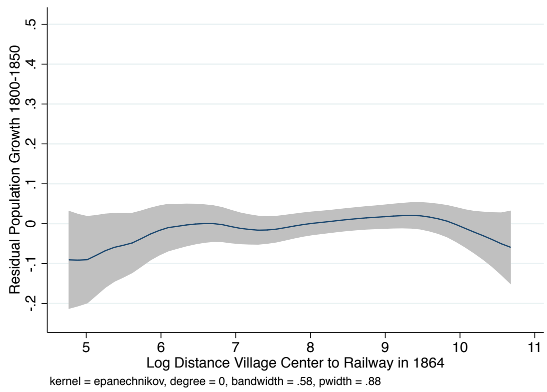
Urbanisation in Switzerland advanced quickly in the second half of the 19th century. This may raise concerns that the effect of railway access was mainly driven by urbanisation forces. We therefore check whether the impact of railway access varies with distance to the urban centres. While distance to the 20 largest cities has a strongly negative impact on population growth rates, the interaction of distance to the 20 largest cities with railway access has no significant effect on the population growth rate (see Table B.6). This alleviates concerns that the railway access dummy primarily picks up urbanisation effects, and suggests that railway access was equally beneficial in peripheral areas and in the direct vicinity of the main urban centres. Finally, Table B.7 excludes municipalities within a 10km perimeter around main nodes, since one may argue that municipalities further away from nodes were less exposed to urbanisation dynamics and "more randomly" assigned. While the results remain robust in the main sample (whole Switzerland, first wave), the estimates become insignificant (albeit being positive) when further reducing the number of observations (pre-railway sample, second wave).

Overall, we consider these results as extensive evidence for the positive population growth effects of obtaining railway access. Complementing the results on the growth effects, we now turn to exploring the distributional consequences of infrastructure expansion in a detailed spatial analysis.

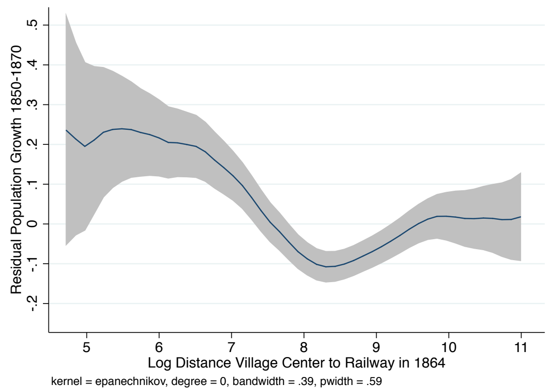
5.3 Displacement Effects and Heterogeneity across Municipalities

Compared to other studies that investigate the impact of railway infrastructure, the small size of Swiss municipalities allows for a detailed spatial evaluation of growth effects. For example, both Atack et al. (2010) and Donaldson and Hornbeck (forthcoming) use US counties as units of analysis, which have a median land area of 1 610 km^2 compared to less than 7 km^2 of a median-sized Swiss municipality.

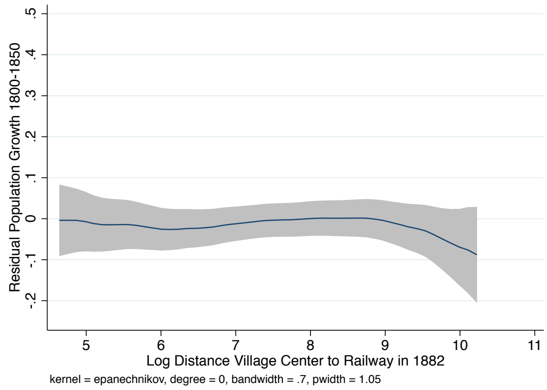
One important question that can be addressed based on the spatially small-scaled data



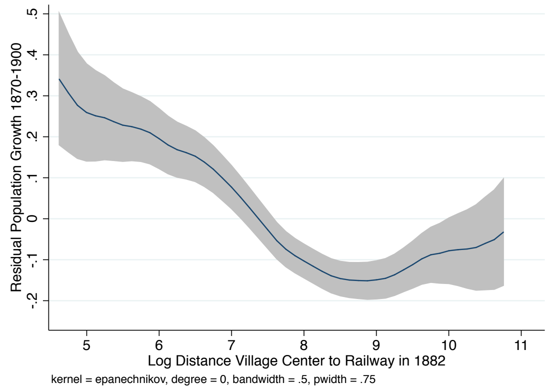
(a) Wave 1: Pre-treatment 1800 to 1850



(b) Wave 1: Post-treatment 1850 to 1870



(c) Wave 2: Pre-treatment 1800 to 1850



(d) Wave 2: Post-treatment 1870 to 1900

Figure 5: Distance Village Centre to Railway and Population Growth, Local Polynomial with 95% Confidence Band.

We add 100m to the village-railway distance to smooth values close to zero. **Residuals:** Calculated based on OLS regression of population growth on controls, i.e. distance to nearest town node, distance to nearest Stephenson-Swinburne node, access to road, access to navigable water, elevation, water power potential, town privilege, population in 1850, area in km^2, district population growth 1800–50 (b. & d.), and cantonal fixed effects. Wave 1: railway construction 1847–64, wave 2: railway construction 1869–82.

relates to the local displacement effects of transportation infrastructure. For instance, Chandra and Thompson (2000) find that US highways led to a local shift of production from unconnected regions to neighbouring regions with highway access. If railway caused such local reorganisations, we would expect positive population growth effects in very close proximity to the railway, and negative growth effects in middle distances from the railway.

Figure 5 shows four local polynomial regressions of residual population growth on the log distance (in meters) from village centres to the railway line in 1864 (1st wave) and 1882 (2nd wave); the samples cover the pre- and post-treatment periods from 1800 to 1850 (pre, both waves), 1850 to 1870 (post, wave 1) and from 1870 to 1900 (post, wave 2). Both graphs for the post-treatment period (i.e. panels b and d), are indeed hump-shaped, supporting the hypothesis of local displacement effects from nearby municipalities to those with direct railway access. Importantly, this pattern only evolved after the construction of railway lines, as the pre-treatment graphs show no relationship between distance to (future) railways and population growth, mitigating endogeneity concerns related to this estimation approach.

Table 6: Distance to Railway (1847-1864) and Annual Population Growth Rates, Cross-Sectional Estimates.

	Pre-Railway Sample[a]			Whole Switzerland	
	1800-50	1850-70	1850-1900	1850-70	1850-1900
	(1)	(2)	(3)	(4)	(5)
Distance Village Centre to Railway 0-2km	0.05	0.12	0.23^{*}	0.15^{*}	0.19^{***}
	(0.07)	(0.13)	(0.10)	(0.06)	(0.05)
Distance Village Centre to Railway 2-4km	0.02	-0.28^{*}	-0.16^{+}	-0.12^{*}	-0.12^{**}
	(0.06)	(0.12)	(0.09)	(0.06)	(0.05)
Distance Village Centre to Railway 4-6km	0.10	-0.29^{*}	-0.25^{**}	-0.16^{**}	-0.20^{***}
	(0.07)	(0.12)	(0.09)	(0.06)	(0.05)
Distance Village Centre to Railway 6-8km	0.13^{*}	-0.37^{**}	-0.36^{***}	-0.19^{**}	-0.28^{***}
	(0.06)	(0.11)	(0.08)	(0.06)	(0.05)
Distance Village Centre to Railway 8-10km	0.07	−0.15	−0.13	−0.03	-0.15^{**}
	(0.07)	(0.13)	(0.09)	(0.07)	(0.05)
Distance Village Centre to Railway 10-12km	0.10	0.17	0.09	0.04	−0.03
	(0.07)	(0.18)	(0.13)	(0.09)	(0.06)
R^2	0.27	0.16	0.30	0.18	0.29
Observations	903	903	900	2790	2770

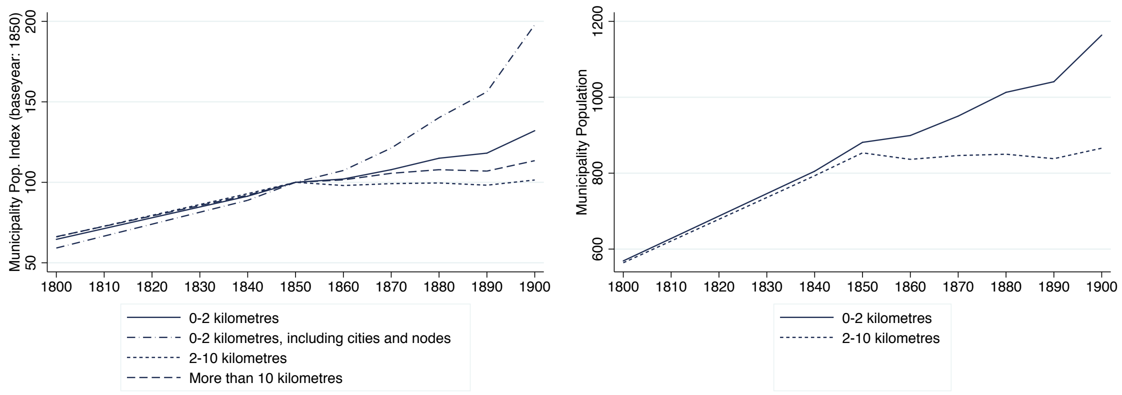
Notes: The controls used are distance to the nearest city (log), distance to the nearest Stephenson-Swinburne node (log), subsequent railway access (binary), access to main road (binary), access to navigable water (binary), elevation (log), water power potential (binary), town privilege (binary), initial population (log), area in km^2 (log), and annual district population growth 1800-1850. ***Sample:*** Excluding nodes and municipalities affected by railway construction work. ***a***: pre-railway sample available for 4 cantons. Huber-White standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

The graphical illustration nicely reveals that railways had a substantial displacement effect at the very local level. Villages within 2 kilometres distance to the railway line experienced a positive population growth effect of up to 0.25 percentage points per year. Villages in middle distances from the railway, between 2.5 and 10 kilometres, saw a relative decline in population growth, with the most negative effect occuring at a distance of 4 kilometres from the railway. Municipalities further away than 10 kilometres from the railway line were less affected, with residual growth rates reverting to zero.

The displacement effects are even more pronounced for the second wave of railway constructions. Again, the strongest growth stimulus of 0.3 percentage points per year can be observed in municipalities with a railway line close to the village centre. Effects remain positive up to around 1.5 kilometres from the railway line, and turn negative between 2 to 20 kilometres.

To further investigate these patterns, Table 6 provides a spatially disaggregated analysis by including a set of distance dummies. Distance to the railway is again calculated as distance from the village centre of a municipality to the closest railway track, with each distance dummy covering a bandwidth of 2 km.[15] Reproducing the results from the local polynomial regressions in Figure 5, railway only had a positive growth impact on municipalities that were very close to the railway line. Municipalities located more than 2 km from the railway network experienced a slowdown in population growth with the negative effect peaking at 6 to 8 km. The overall impact reverts to zero, for municipalities at a distance of 10 to 12 kilometres from the railway line.

[15] We only present OLS results for this part, since instrumenting a series of distance dummies is beyond the power of our instrument. The results in column (1) of Table 6 do not point towards selection effects.



(a) Population Development (Index: 1850=100) (b) Municipality Population Levels

Figure 6: Municipality population levels and index over time, conditional on distance of village centre from railway line in 1864
Notes: Panel (a) depicts indexed population levels with 1850 as a base year (1850 = 100). All groups are averages of the respective municipalities. Panel (b) presents the average of population levels the two groups of municipalities.

We also check the robustness of these results with respect to adapting our main explanatory variable: Section B.2.6 in the appendix replicates these results by substituting distance to the closest railway line with distance to the closest railway station. This does neither change the main insights from the local polynomial regression nor from the regressions modelling distance with a set of dummies.

Taken together, this strongly points towards a local reorganisation of economic activity as municipalities in the direct vicinity of railway tracks (2 km–10 km) experienced a slowdown in population growth, suggesting that people moved closer to the railway line after it went into service. We are not aware of any study that present such highly localized patterns of reorganization caused by railway investments. The pattern is in line with the theoretical prediction by Redding and Turner (2015) that labor relocates to locations with lower trade costs, until real wages are equalized across all locations. Qualitatively, our findings also strengthen the results by Chandra and Thompson (2000) who find that interstate highways raise earnings in counties that benefit directly from improved access, while total earnings fall in adjacent counties, not connected by the highway.

Finally, Figure 6 depicts population indices and population levels for municipalities grouped by their distance to the closest railway line in 1864. Panel (a) shows indexed population levels (i.e. index in 1850=100) for municipalities close to the railway (0 to 2 kilometres; with and without the main nodes), for neighbouring municipalities with a distance ranging between 2 and 10 kilometres from the railway, and municipalities further than 10 kilometres from the railway. It highlights two points: Again, the pre-treatment trends in population growth are very similar across the groups.[16] This suggest that both rural and urban areas had a similar growth path prior to the railway construction. Second, railway investments led to a divergence in population growth rates between those municipalities crossed by a railway line, and those municipalities a bit further away. This

[16] Figure A.5 in the appendix illustrates the spatial distribution of these three groups of municipalities.

second point is even stronger emphasized by Panel (b), which plots actual population levels over time. The average population size was quasi identical across the two groups in the pre-railway period. Yet, railway lines stabilized or even fostered population growth for municipalities very close to the tracks, while it levelled off in neighbouring municipalities. This distinct divergence of population levels nicely illustrates the long-term displacement effects towards railway lines.

6 Conclusion

This study on railway expansion and population growth in 19th century Switzerland establishes two findings: On the one hand, railway access indeed may be considered *a* track to (population) growth. Comprehensive evidence suggest that being connected to the railway network increased a municipality's annual population growth rate by about 0.4 percentage points relative to the growth rate of municipalities without railway access. This translates into an additional population count of 23% after 50 years. On the other hand, the "fast track to growth" notion has to be used with care, since railway had a detrimental impact on neighbouring municipalities within a perimeter of 2 to 10 km of the railway lines. We interpret this finding as strong evidence for (highly) localized displacement effects that shifted economic activity closer to the transportation network and also to cities.

Adding to the well-established findings on railway access and city growth, our study of Switzerland complements the recent literature on the impact of early railway technology in western countries. We show that not only urban centres but also small rural municipalities along the main lines benefited from railway access. Yet, the estimated effects in rural areas are less than half that reported for cities, substantiating the notion that railway access primarily promoted growth in cities and regional centres, while the impact was considerably smaller in rural municipalities along the rail tracks. Moreover, our findings also reveal that unconnected municipalities in the close vicinity of railway lines experienced a slump in population growth rates, most likely due to displacement effects. This highlights the importance of considering distributional consequences of large-scale infrastructure investments.

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A Data Appendix

A.1 Description of Main Variables and Summary Statistics

Table A.1: Variable Description & Data Sources

Municipal Level		
Annual Population Growth	$100 \cdot (log(POP_{i,t2}) - log(POP_{i,t1}))/(t2 - t1)$	Census (1850, 60, 70, 80, 88, 1900), Schuler and Schluchter (in progress)
Treatment Variable		
Railway Access	Binary indicator. Equals one if railway intersects a municipality's boundary.	GIS-Dufour (Egli et al., 2005)
Distance to Railway	Natural logarithm of the distance between a municipality's village centre and the closest railway line in meters.	GIS-Dufour (Egli et al., 2005)
Control Variables		
Distance to Town Node	Natural logarithm of the distance between a municipality's centroid and the closest town node's centroid in kilometres. Town nodes are defined as Switzerland's 20 largest towns in 1850.	Swisstopo (2007)
Distance to Stephenson-Swinburne Node	Natural logarithm of the distance between a municipality's centroid and the closest Stephenson-Swinburne node in kilometres. If the closest Stephenson-Swinburne node is also a town node, we compute the distance based on the second closest Stephenson-Swinburne node.	Swisstopo (2007)
Access to Main Road in 1850	Binary indicator. Equals one if road of primary importance intersects a municipality's boundary, see A.5.	GIS-Dufour (Egli et al., 2005)
Access to Navigable Water	Binary indicator. Equals one if municipality adjoins navigable water.	Swisstopo (2007)
Elevation	Natural logarithm of the mean elevation (in 100m) calculated based on a 25 m x 25 m height model.	Swisstopo (2004)
Water Power Potential	Binary indicator. Equals one if a river with a water flow of at least 1 m^3/s crosses a municipality and – in doing so – overcomes a height difference of 10m or more, see A.4.	Swisstopo (2007), Pfaundler and Schönenberger (2013)
Town Privilege	Binary indicator. Equals one if municipality holds the historical town status.	Guyer (1960)
Population in 1850	Natural logarithm of a municipality's population in 1850.	Census (1850)
Municipal Area	Natural logarithm of municipal area in square kilometres.	Swisstopo (2007)
District Pop. Growth 1800–50	$100 \cdot (log(POP_{d,t2}) - log(POP_{d,t1}))/50$	Schluchter (1988), Census

Table A.2: Descriptive Statistics

Municipal Level	Observations	Mean	Std. Dev.	Min.	Max.
Annual Population Growth, 1850–1900 (cross-section)	2844	0.15	0.66	−2.43	5.90
Annual Population Growth, 1850–1900 (pooled)	14 330	0.15	1.27	−16.05	22.23
Treatment Variable					
Railway Access, 1850–1900 (pooled)	17 322	0.22	-	0	1
LN(Dist. Village Centre to Rail), 1850–1900 (pooled)	17 322	2.08	1.21	0.01	4.80
Control Variables					
LN(Distance to Town Node)	2854	2.90	0.63	0.68	4.44
LN(Distance to Stephenson-Swinburne Node)	2854	3.08	0.74	0.21	4.64
Access to Main Road in 1850	2887	0.38	-	0	1
Access to Navigable Water	2887	0.06	-	0	1
LN(Elevation in 100m)	2887	1.97	0.49	0.78	3.40
Water Power Potential	2887	0.42	-	0	1
Town Privilege	2887	0.04	-	0	1
LN(Population) in 1850	2847	6.25	0.92	3.56	10.64
LN(Municipal Area)	2887	2.00	1.04	−1.14	5.64

A.2 Details on Construction of Least-Cost Paths

Below, we detail our procedure of constructing least-cost paths (as shown in Figure A.1) for all main railway lines built between 1847 and 1900. Our sensitivity checks are described in the final step.

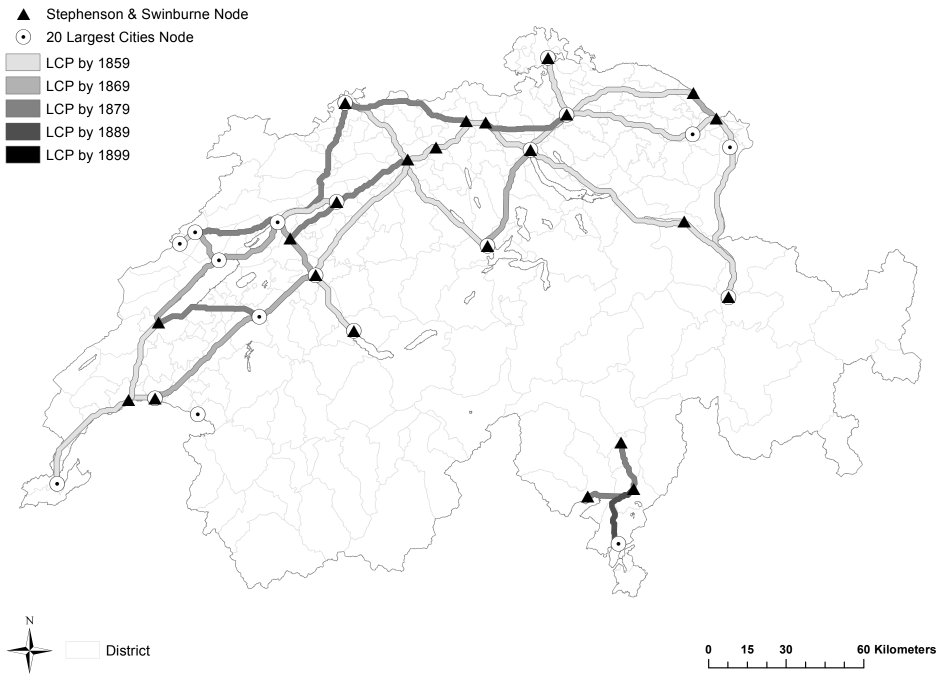


Figure A.1: Least-Cost Paths for Main Lines by Decade of Their Opening

Notes: Least-cost paths, which represent a virtual cost-efficient railway line computed with GIS-software. For better readability least-cost paths are displayed with a width of 2km.

1. Selection of main nodes (as listed in Table A.3) based on the following criteria: First, the 20 most populous municipalities in 1850 that held the historical town status (source: Guyer, 1960). Second, 23 locations listed as central traffic junctions in plans delivered to the federal government by Robert Stephenson and Henry Swinburne in 1850 (see Figure A.2).

2. Selection of main lines, i.e. railway lines that were primarily built to connect two main nodes (source: Wägli, 1998; Weissenbach, 1913). This explicity excludes routes that established inter-node connections gradually over long periods of time.

3. Extracting information on construction costs of 48 railway lines built between 1847 and 1881 from the Swiss Traffic Atlas (source: NOB, 1883).

4. Calculating the mileage as well as gradient (average degree of slopes per km) of the 48 railway lines based on a 25 m x 25 m height model for Switzerland (source: Swisstopo, 2004).

Table A.3: Main Nodes

Municipality	**Population in 1850**	**RW Access**	**Municipality**	**Population in 1850**	**RW Access**
Among 20 Largest Towns & Listed as Node in 1850-Expertise					
Zurich	41585	1847	Luzern	10068	1859
Bern	29670	1857	Schaffhausen	8477	1857
Basel	27844	1844/54	Chur	6183	1858
Lausanne	17108	1856	Thun	6019	1859
Winterthur	13651	1855	Solothurn	5370	1857
Among 20 Largest Towns			Listed as Node in 1850-Expertise		
Geneva	37724	1858	Aarau	4657	1856
St. Gallen	17858	1856	Yverdon	3619	1855
Chaux-de-Fonds	12638	1857	Morges	3241	1855
Fribourg	9065	1862	Bellinzona	3209	1874
Le Locle	8514	1857	Baden	3159	1847
Neuchatel	7901	1859	Locarno	2944	1874
Altstaetten	6492	1858	Biasca	2035	1874
Lugano	5939	1874	Walenstadt	1868	1859
Biel	5609	1857	Rorschach	1751	1856
Vevey	5201	1861	Olten	1634	1856
			Brugg	1581	1856
			Lyss	1568	1864
			Romanshorn	1408	1855

Notes: The 20 largest towns are selected based on the Swiss census and Guyer (1960). The list of nodes as suggested in the 1850-expertise by Stephenson and Swinburne is taken from Weissenbach (1913). Population figures are based on municipality border zoning from January 2000.

5. Regression of railway construction costs on average gradient:
   $Cost\ p.\ km_i = \alpha + \beta \cdot degree\ p.\ km_i + \epsilon_i$.
   We obtain 179'939 (s.e.=33'655) for $\hat{\alpha}$ and 14'677 (s.e.=5'499) for $\hat{\beta}$. These values serve us as main parameters when simulating the least-cost paths in ArcGIS: We interpret $\hat{\alpha}$ as costs related to track length (cost per additional kilometer) and $\hat{\beta}$ as costs related to rough terrain (km cost per average gradient measured in degrees).

6. Deriving the costs of building bridges based on the regression's residual (step 5) for a 2 km track section that includes a 216 m long bridge over the river Rhine in Basel. We obtain costs of 800 000 CHF for the rail bridge in Basel, which we linearly scale down for smaller rivers based on federal water quantity statistics (source: Pfaundler and Schönenberger, 2013). The main purpose of introducing this parameter is to prevent multiple river-crossing, which were evidently expensive.

7. Compilation of a cost-raster for Switzerland in ArcGIS that calculates hypothetical railway construction costs for each 200m x 200m grid cell based on the above parameters (i.e. costs of distance, costs of gradients, costs of bridges). We use the official height model and aquatic maps from Swisstopo to assign costs to each cell.

8. Calculating hypothetical least cost paths for main lines selected in step 2 using ArcGIS tool "Least Cost Path" and cost-raster from step 7.

9. Assigning each least-cost path an opening date, which corresponds with the opening date of the actual railway line.
10. Intersecting the least-cost paths with municipal boundaries. This produces an indicator, LCP^w, coded 1 if a municipality is traversed by a least-cost path during the construction wave w, and coded 0 if all the least-cost paths bypass outside the municipality in the given time span.
11. *Sensitivity checks:* We simulate four additional sets of least-cost paths by changing the following values (one by one): 1. bridge cost parameter = 600'000; 2. bridge cost parameter = 1'000'000, 3. slope parameter= 20'800 (i.e. benchmark + 1 s.e.), 4. slope parameter=9'200 (benchmark - 1 s.e.). As shown in Table A.4, the least-cost paths are almost identical to the benchmark for alternatives 1.–3., with less than 1% of municipalities changing status between traversed/bypassed. When lowering the slope parameter to 9'200 (alternative 4.), this changes about 5% of the municipalities' classifications. The main results regarding the impact of railway access on population growth are not altered when using these alternative parametrizations B.2.

Table A.4: Classification of Municipalities Based on Various Parameter Values

	Bridge=1Mio. Slope=15K KM Cost=180K		Bridge=600K Slope=15K KM Cost=180K		Bridge=800K Slope=20.8K KM Cost=180K		Bridge=800K Slope=9.2K KM Cost=180K	
	LCP=0	LCP=1	LCP=0	LCP=1	LCP=0	LCP=1	LCP=0	LCP=1
Main LCP=0	2,342	6	2,345	3	2,339	9	2,276	72
Main LCP=1	3	536	2	537	9	530	75	464

Notes: This table compares the LCP-classification of municipalities in 1900 based on "Least Cost Path" simulations in ArcGIS for various cost parameters. The LCP-parametrization as used in our main analysis (shown in the table's rows) serves as benchmark.

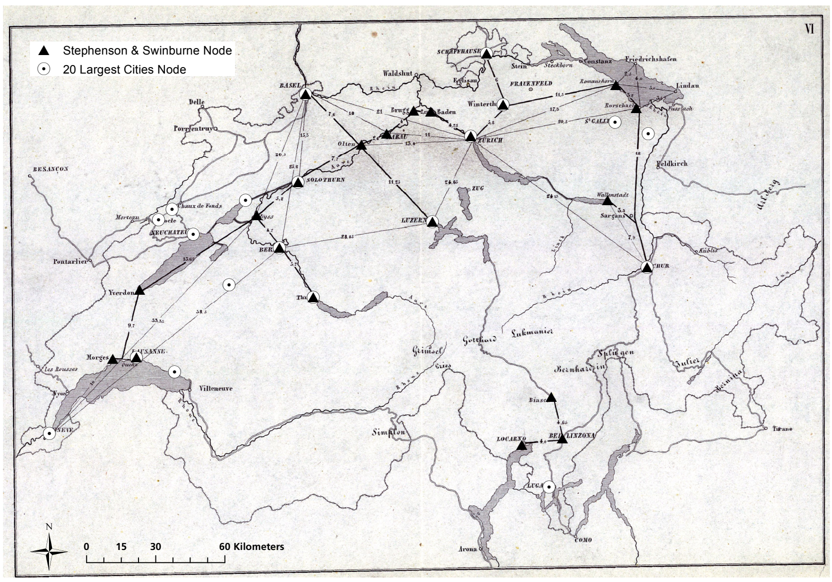


Figure A.2: Original Stephenson & Swinburne Plan with Main Nodes

A.3 Details on Construction of Treatment Indicator Based on Railway Stations

We determine the location of each railway station that was opened between 1847 and 1900 based on the following procedure:

1. Collection of data on municipality infrastructure from Ziehr (1991); the encyclopaedia lists for each municipality public service milestones such as the opening of postal services, introduction of telegraphic services, adoption of electricity and the opening of railway stations.
2. Identification of municipalities where the list derived from Ziehr (1991) does not accord with our main source on the Swiss railway network, i.e. Egli et al. (2005).
3. Consulting the Historic Lexicon of Switzerland[17] to double check the list of municipalities with contradicting information.
4. Visual search for railway stations in the historic Dufour- and Siegfried-Maps to settle all remaining cases with conflicting information.
5. Locating railway stations (according to our consolidated list) by combining information on today's railway stations (source: Swisstopo), and the historic railway network.
6. Final check of the railway stations' location using the digitized Dufour Map of 1900. Since the Swiss railway network was almost completed by 1900, most stations remained at their original spot. We manually re-position stations that changed their location.

A.4 Details on Construction of Indicator for Hyropower Potential

Early Swiss industrial development used hydropower as an important source to run industrial machines. Since Switzerland itself had no coal deposits, wood was a limited power source and there was no high-capacity means of transportation for fossil fuels, water was the main source of power for industrial development prior to the railway era (Schnitter, 1992). For each municipality we define a potential for hydroelectric power based on existing hydropower technologies. The main parameters determining the potential for hydropower are the water cumulative flows and the gradient that the water falls. The Francis Turbine was invented in the year 1849 by James B. Francis and the most advanced technology at the beginning of the railway era in Switzerland. Taking the technical constraints of the Francis Turbine into account, we define a simplified indicator for hydro power potential based on two conditions: First, the water flow has to reach a minimum of at least 1 m^3/s. Second, the height difference between the point of entry and exit of a river flowing through

[17]Historisches Lexikon der Schweiz, available online at http://www.hls-dhs-dss.ch/index.php

a municipality has to be at least 10 m. If a watercourse satisfying both conditions runs through a municipality, it is assigned value 1, and otherwise 0. We construct this variable based on detailed information on water drain measured for each water body in Switzerland combined with data on larger river water flows measured by metering stations.[18] Using GIS we determine for every water body the point of entry and exit for each municipality and the height difference between entry and exit point. We then code municipalities as having the potential for industrial hydropower generation using the parameters mentioned above.

A.5 Details on Construction of Road Access Indicator

We use information on the development of the road network in the 18th and 19th century from the GIS-Dufour project (Egli et al., 2005). GIS-Dufour documents all roads and their classification according to the cantonal road laws. The road laws were enacted in most cantons in the years 1830–1840 and they differ from canton to canton. However, most cantonal laws include a classification on roads of primary importance, i.e. class 1 roads. To control for road accessibility we use information on the class 1 road network, and identify municipalities with access to such a class 1 roads. Figure A.3 shows the 1850-network of roads of primary importance.

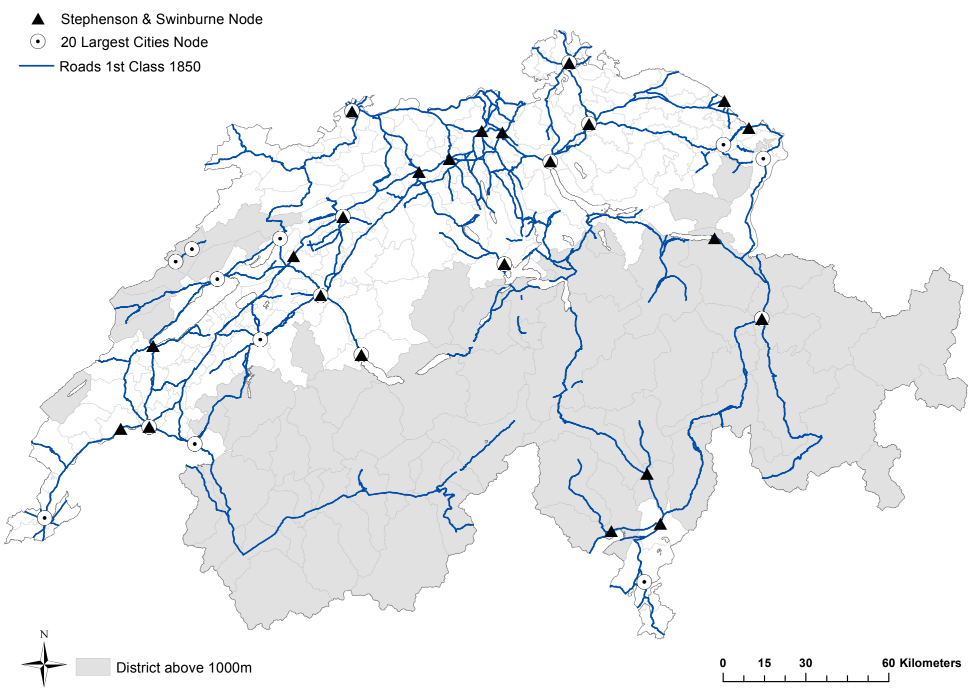


Figure A.3: Roads of Primary Importance in 1850
Notes: Road network displaying roads with a classification 1 according to the cantonal road laws in 1850, based on the GIS-Dufour project (Egli et al., 2005).

[18] Data on water drain is available at http://www.bafu.admin.ch/wasser/13462/13496/15016/index.html?lang=de (Pfaundler and Schönenberger, 2013); data from metering stations along larger Swiss rivers is available at http://www.hydrodaten.admin.ch/de/stationen-und-daten.html.

A.6 Railway Network Maps

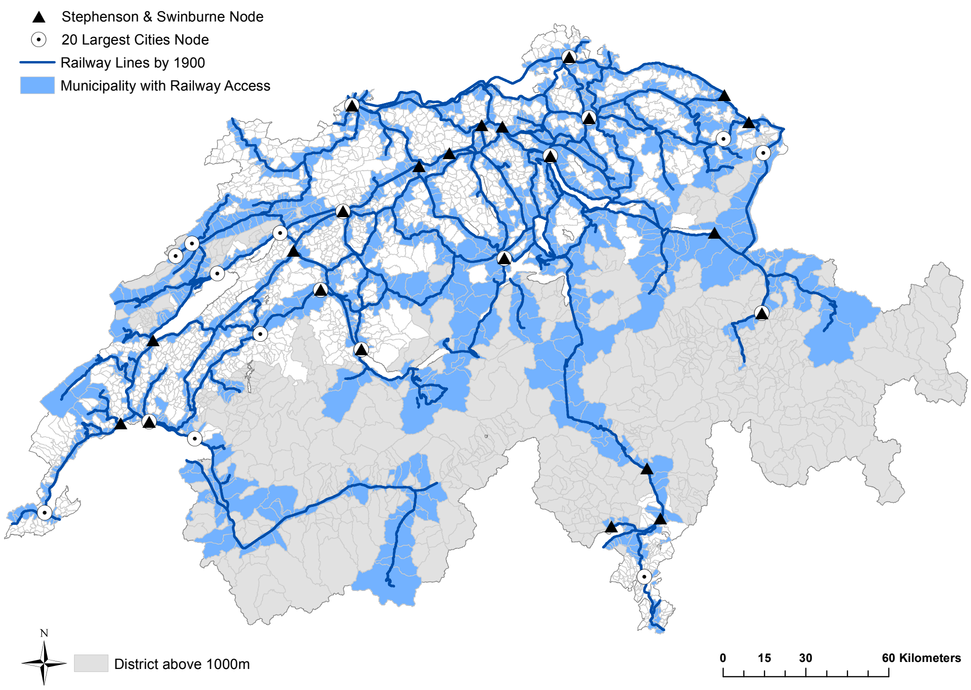


Figure A.4: Swiss Railway Network by 1900

Notes: The map shows the Swiss railway network as completed by 1900. The source of digitized railway lines is the project "GIS-Dufour" (Egli et al., 2005).

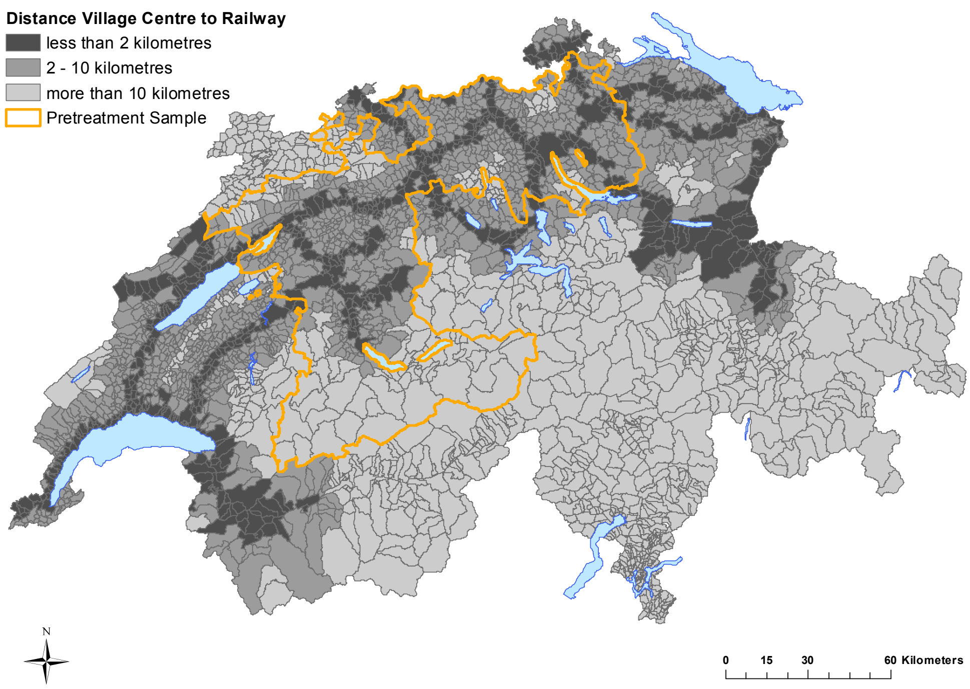


Figure A.5: Distance Village Centre to Railway in 1864

Notes: Least-cost paths, which represent a virtual cost-efficient railway line computed with GIS-software. For better readability least-cost paths are displayed with a width of 2km.

B Empirical Appendix

B.1 Comprehensive Table Including Controls

Table B.1: The Impact of Railway Access (1847–64) on Annual Population Growth Rates (1850–1900), Cross-Sectional Estimates at the Municipal Level

	OLS (1)	IV (2)	IV, First Stage (3)
Railway Access 1847–64	0.41***	0.39***	
	(0.04)	(0.10)	
LCP 1847–64			0.33***
			(0.03)
Road Access 1850	0.05*	0.06+	0.16***
	(0.02)	(0.03)	(0.01)
Water Access	0.07	0.07	0.13***
	(0.06)	(0.06)	(0.03)
Log Elevation	–0.25***	–0.25***	–0.07**
	(0.05)	(0.05)	(0.02)
Water Power Potential	0.09***	0.09***	0.04**
	(0.03)	(0.03)	(0.01)
Log Distance to Town Node	–0.24***	–0.24***	–0.02
	(0.03)	(0.03)	(0.01)
Log Distance to Steph.-Swinb. Node	0.04+	0.04+	–0.01
	(0.02)	(0.02)	(0.01)
Log Population 1850	–0.05	–0.05	0.07***
	(0.03)	(0.03)	(0.01)
Log Area	0.12***	0.12***	–0.01
	(0.03)	(0.03)	(0.01)
Town Privilege	0.36***	0.36***	0.07+
	(0.07)	(0.07)	(0.04)
Subsequent Railway Access	0.29***	0.28***	–0.23***
	(0.03)	(0.04)	(0.01)
District Pop. Growth 1800–50	–1.58	–1.58	1.41
	(7.45)	(7.41)	(2.62)
R^2	0.28	–	0.39
Observations	2770	2770	2770

Notes: The dependent variable is annual population growth in percent. ***Sample:*** All municipalities, excluding nodes and municipalities affected by railway construction work. The instrument is based on a least-cost path for railway lines between the 20 largest cities and Stephenson-Swinburne nodes. Huber-White standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

B.2 Robustness

B.2.1 Alternative LCP Parametrization

Table B.2: Robustness: The Impact of Railway Access on Annual Population Growth Rates, Main IV-Estimates with LCP based on Slope=9.2K & Bridge=800K.

	CS: Wave 1		CS: Wave 2			Panel	
	1800–1850[a]	1850–1900	1800–1850[a]	1870–1900		1840–1900[a]	1850–1900
	(1)	(2)	(3)	(4)		(5)	(6)
IV, Second Stage: Annual Population Growth Rates and Railway Access							
Rail Access	0.18	0.41***	−0.16	1.05***	L.Rail Access	0.51*	0.56***
	(0.20)	(0.12)	(0.16)	(0.29)		(0.22)	(0.17)
Observations	903	2770	747	2344	Observations	4926	13651
Canton FE	Yes	Yes	Yes	Yes	Canton Time FE	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Municipal FE	Yes	Yes
IV, First Stage: Actual Railway Access and Least-Cost Paths							
Least-Cost Path	0.19***	0.31***	0.26***	0.23***	Least-Cost Path	0.30***	0.34***
	(0.04)	(0.03)	(0.05)	(0.04)		(0.04)	(0.03)
R^2	0.27	0.38	0.25	0.30	R^2	0.24	0.26
Observations	903	2770	747	2344	Observations	4926	13651

Notes: The controls used in columns (1)–(4) are distance to the nearest city (log), subsequent railway access (binary), access to main road (binary), access to navigable water (binary), elevation, water power potential (binary), town privilege (binary), initial population (log), area in km^2, and pre-railway population growth (except columns 1 & 3). *a*: pretreatment sample available for 4 cantons only. The instrument is based on a least-cost path for railway lines between the 20 largest cities and Stephenson-Swinburne nodes. Huber-White standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

B.2.2 Pre-Treatment Sample

Table B.3: The Impact of Railway Access (1847–64) on Annual Population Growth Rates, Cross-Sectional Estimates (Sample: Municipalities with Pre-Railway Data Available)

	Long Run		10 Year Periods				
	1800–50[a]	1850–1900	1850–60	1860–70	1870–80	1880–90	1890–1900
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
OLS: Annual Population Growth Rates and Railway Access							
Rail Access 1847–64	0.00	0.56***	0.24**	0.43***	0.51***	0.42***	0.76***
	(0.04)	(0.06)	(0.09)	(0.11)	(0.09)	(0.10)	(0.12)
R^2	0.26	0.29	0.07	0.11	0.18	0.14	0.17
Observations	903	900	903	903	898	898	900
IV, Second Stage: Annual Population Growth Rates and Railway Access							
Rail Access 1847–64	0.15	0.95***	0.33	0.57*	0.70+	0.68+	1.28**
	(0.15)	(0.24)	(0.28)	(0.26)	(0.36)	(0.35)	(0.49)
Observations	903	900	903	903	898	898	900
IV, First Stage: Actual Railway Access 1847–64 and Least-Cost Paths							
LCC 1847–64	0.25***	0.25***	0.33***	0.33***	0.27***	0.27***	0.25***
	(0.04)	(0.04)	(0.05)	(0.05)	(0.05)	(0.05)	(0.04)
R^2	0.29	0.29	0.21	0.22	0.26	0.27	0.29
Observations	903	900	903	903	898	898	900

Notes: The dependent variable is annual population growth in percent. The controls used are distance to the nearest city, distance to the nearest Stephenson-Swinburne node, subsequent railway access, access to main road, access to navigable water, elevation, water power potential, town privilege, population in 1850, area in km^2, initial population, annual population growth 1800–1850 (except column 1), and cantonal fixed effects. ***Sample:*** Excluding nodes and municipalities affected by railway construction work. The instrument is based on a least-cost path for railway lines between the 20 largest cities and Stephenson-Swinburne nodes. Huber-White standard errors in parentheses.. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

B.2.3 Railway Stations as Treatment Indicator

Table B.4: Robustness: The Impact of Railway Stations on Annual Population Growth Rates, Main IV-Estimates

	CS: Wave 1		CS: Wave 2			Panel	
	1800–1850[a]	1850–1900	1800–1850[a]	1870–1900		1840–1900[a]	1850–1900
	(1)	(2)	(3)	(4)		(5)	(6)
IV, Second Stage: Annual Population Growth Rates and Railway Access							
Rail Station	0.23	0.60***	–0.35+	0.92**	L.Rail Station	0.66*	0.66**
	(0.21)	(0.16)	(0.19)	(0.35)		(0.28)	(0.21)
Observations	903	2770	809	2516	Observations	4926	13651
Canton FE	Yes	Yes	Yes	Yes	Canton Time FE	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Municipal FE	Yes	Yes
IV, First Stage: Actual Railway Access 1847-1864 and Least-Cost Paths							
Least-Cost Paths	0.18***	0.23***	0.25***	0.20***	Least-Cost Paths	0.24***	0.26***
	(0.04)	(0.03)	(0.05)	(0.04)		(0.04)	(0.03)
R^2	0.19	0.28	0.20	0.24	R^2	0.18	0.20
Observations	903	2773	809	2516	Observations	4926	13651

Notes: The controls used in columns (1)–(4) are distance to the nearest city (log), subsequent railway access (binary), access to main road (binary), access to navigable water (binary), elevation, water power potential (binary), town privilege (binary), initial population (log), area in km^2, and pre-railway population growth (except columns 1 & 3). *a*: pretreatment sample available for 4 cantons only. The instrument is based on a least-cost path for railway lines between the 20 largest cities and Stephenson-Swinburne nodes. Huber-White standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

B.2.4 Municipalities in Districts below 1 000 Meters

Table B.5: The Impact of Railway Access (1st & 2nd Wave) on Annual Population Growth Rates, Cross-Sectional Estimates (Sample: Mean District Elevation below 1 000 m.a.s.l.)

	1st Wave: 1847–64			2nd Wave: 1869–82	
	1800–50[a]	1850–1900		1800–50[a]	1870–1900
	(1)	(2)		(3)	(4)
OLS: Annual Population Growth Rates and Railway Access					
Rail Access 1847–64	–0.02	0.42***	Rail Access 1869–82	–0.05	0.38***
	(0.04)	(0.04)		(0.04)	(0.05)
R^2	0.27	0.30	R^2	0.20	0.27
Observations	826	2018	Observations	747	1669
IV, Second Stage: Annual Population Growth Rates and Railway Access					
Rail Access 1847–64	0.13	0.42***	Rail Access 1869–82	–0.23+	0.43*
	(0.16)	(0.12)		(0.12)	(0.17)
Observations	826	2018	Observations	747	1669
IV, First Stage: Actual Railway Access 1847–64 and Least-Cost Paths					
LCP 1847–64	0.24***	0.31***	LCP 1869–82	0.28***	0.38***
	(0.05)	(0.03)		(0.05)	(0.04)
R^2	0.29	0.37	R^2	0.30	0.33
Observations	826	2018	Observations	747	1669

Notes: The controls used are distance to the nearest town node, distance to the nearest Stephenson-Swinburne node, subsequent railway access, access to main road, access to navigable water, elevation, water power potential, town privilege, population in 1850, area in km^2, pre-railway population growth, and cantonal fixed effects. ***Sample:*** Municipalities of districts with a mean elevation below 1 000 m.a.s.l., excluding nodes and municipalities affected by railway construction work. *a*: Pre-railway sample available for 4 cantons (ZH, BE, SO, AG). The instrument is based on a least-cost path for railway lines between the 20 largest cities and Stephenson-Swinburne nodes. Huber-White standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

B.2.5 Municipalities Adjacent to Cities

Table B.6: The Impact of Railway Access (1847–64) and Interaction Terms on Annual Population Growth Rates, Cross-Sectional Estimates at the Municipal Level

	Long Run 1850–1900			
	OLS	OLS	IV	IV
	(1)	(2)	(3)	(4)
Annual Population Growth and Railway Access				
Rail Access 1847–64	0.41***	0.40***	0.39***	0.38***
	(0.04)	(0.04)	(0.10)	(0.10)
Rail Access 1847–64 x Distance 20 Cities		−0.07		−0.05
		(0.06)		(0.14)
R^2	0.28	0.28	–	–
Observations	2770	2770	2770	2770
FS 1: F-statistic	–	–	146.87	86.01
FS 2: F-statistic	–	–	–	76.78

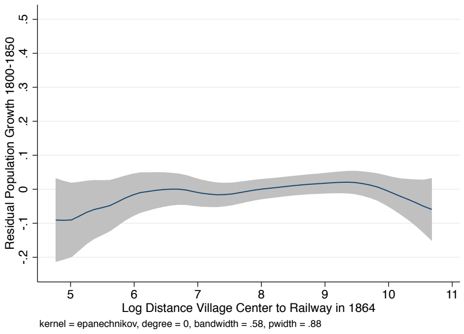
Notes: The dependent variable is the annual population growth rate in percent. The controls used are distance to the nearest town node, distance to the nearest Stephenson-Swinburne node, subsequent railway access, access to main road, access to navigable water, elevation, water power potential, town privilege, population in 1850, area in km^2, annual district population growth 1800–1850, and cantonal fixed effects. ***Sample:*** All municipalities of Switzerland, excluding nodes and municipalities affected by railway construction work. The instrument is based on a least-cost path for railway lines between the 20 largest cities and Stephenson-Swinburne nodes. Huber-White standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

Table B.7: Robustness: The Impact of Railway Access on Annual Population Growth Rates, Main IV-Estimates for a Sample excluding 10km Buffers around Nodes

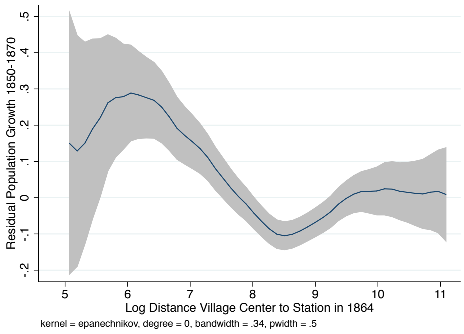
	CS: Wave 1		CS: Wave 2			Panel	
	1800–1850[a]	1850–1900	1800–1850[a]	1870–1900		1840–1900[a]	1850–1900
	(1)	(2)	(3)	(4)		(5)	(6)
IV, Second Stage: Annual Population Growth Rates and Railway Access							
Rail Access	0.11	0.39**	−0.08	0.19	L. Rail Access	0.09	0.30+
	(0.61)	(0.14)	(0.20)	(0.29)		(0.60)	(0.17)
Observations	509	1822	442	1589	Observations	2664	8916
Canton FE	Yes	Yes	Yes	Yes	Canton Time FE	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Municipal FE	Yes	Yes
IV, First Stage: Actual Railway Access and Least-Cost Paths							
Least-Cost Path	0.21***	0.33***	0.33***	0.30***	Least-Cost Path	0.30***	0.39***
	(0.07)	(0.04)	(0.07)	(0.05)		(0.06)	(0.04)
R^2	0.27	0.37	0.33	0.35	R^2	0.24	0.26
Observations	509	1825	442	1589	Observations	2664	8916

Notes: The controls used in columns (1)–(4) are distance to the nearest city (log), subsequent railway access (binary), access to main road (binary), access to navigable water (binary), elevation, water power potential (binary), town privilege (binary), initial population (log), area in km^2, and pre-railway population growth (except columns 1 & 3). ***a***: pretreatment sample available for 4 cantons only. The instrument is based on a least-cost path for railway lines between the 20 largest cities and Stephenson-Swinburne nodes. Huber-White standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

B.2.6 Displacement Effects Using Railway Stations

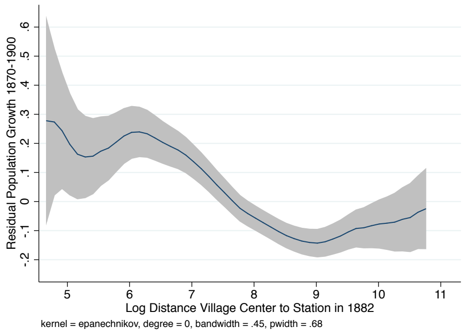


(a) Wave 1: Pre-treatment 1800 to 1850



(b) Wave 1: Post-treatment 1850 to 1870

(c) Wave 2: Pre-treatment 1800 to 1850



(d) Wave 2: Post-treatment 1870 to 1900

Figure B.1: Distance Village Centre to Railway and Population Growth, Local Polynomial with 95% Confidence Band.
We add 100m to the village-railway distance to smooth values close to zero. **Residuals:** Calculated based on OLS regression of population growth on controls, i.e. distance to nearest town node, distance to nearest Stephenson-Swinburne node, access to road, access to navigable water, elevation, water power potential, town privilege, population in 1850, area in km^2, district population growth 1800–50 (b. & d.), and cantonal fixed effects. Wave 1: railway construction 1847–64, wave 2: railway construction 1869–82.

Table B.8: Distance to Railway Stations (1847-1864) and Annual Population Growth Rates, Cross-Sectional Estimates.

	Pre-Railway Sample[a]			Whole Switzerland	
	1800-50	1850-70	1850-1900	1850-70	1850-1900
	(1)	(2)	(3)	(4)	(5)
Distance Village Centre to Station 0-2km	0.05	0.11	0.24^{*}	0.14^{*}	0.22^{***}
	(0.07)	(0.12)	(0.09)	(0.06)	(0.05)
Distance Village Centre to Station 2-4km	0.01	-0.25^{*}	-0.08	-0.13^{*}	-0.08^{+}
	(0.06)	(0.11)	(0.08)	(0.06)	(0.05)
Distance Village Centre to Station 4-6km	0.09	-0.33^{**}	-0.25^{**}	-0.20^{***}	-0.19^{***}
	(0.07)	(0.11)	(0.08)	(0.06)	(0.05)
Distance Village Centre to Station 6-8km	0.12^{+}	-0.40^{***}	-0.35^{***}	-0.21^{***}	-0.29^{***}
	(0.06)	(0.10)	(0.08)	(0.06)	(0.05)
Distance Village Centre to Station 8-10km	0.09	-0.27^{*}	-0.20^{*}	-0.10	-0.18^{***}
	(0.06)	(0.12)	(0.08)	(0.06)	(0.05)
Distance Village Centre to Station 10-12km	0.09	-0.01	0.00	-0.06	-0.09
	(0.07)	(0.16)	(0.11)	(0.08)	(0.06)
R^2	0.27	0.15	0.29	0.18	0.29
Observations	903	903	900	2790	2770

Notes: The controls used are distance to the nearest city (log), distance to the nearest Stephenson-Swinburne node (log), subsequent railway access (binary), access to main road (binary), access to navigable water (binary), elevation (log), water power potential (binary), town privilege (binary), initial population (log), area in km^2 (log), and annual district population growth 1800-1850. ***Sample:*** Excluding nodes and municipalities affected by railway construction work. ***a***: pre-railway sample available for 4 cantons. Huber-White standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

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Tel: +44 (0)20 7955 7673 Email info@cep.lse.ac.uk
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