An Accessibility Approach to Railways and Municipal Population Growth, 1840-1930*

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Abstract

In the nineteenth century, railway networks strongly improved accessibility. In this paper we examine the impact of accessibility improvements on municipal population growth in the Netherlands between 1840 and 1930, using census data. By mapping a multimodal transport network and calculating the shortest travel time between all municipalities, we generate an accessibility indicator which is strongly influenced by railway connections. The regressions show that high rail accessibility levels are positively related to municipal population growth from 1880 onwards. The impact of rail accessibility was stronger at the end of the nineteenth century, as industrialization took off. The overall impact of rail on population growth has been modest, however. In our model, crowding and urbanization effects dominate.

Keywords: Cliometrics, Railways, Accessibility, Municipalities, Population growth.

1. Introduction

In most Western countries, the first railway lines were constructed in the middle of the nineteenth century. Up until then, high transport costs limited overland transport of freight and passengers. The emergence of the railway network changed this picture dramatically. Generalized transport costs decreased and markets became more integrated. We would expect higher regional accessibility levels to boost regional economic growth. In this study, we test this hypothesis for the Netherlands during the period 1840 – 1930.

In the last decades, much empirical research has been done on the economic effects of new infrastructure. Studies focus on either macroeconomic or disaggregated data. In two seminal articles Aschauer (1989a,b) follows a macroeconomic approach by regressing productivity growth of countries on non-military government investments. He finds a strong positive relation. Several authors have done similar studies with sometimes rather different results (see Flores de Frutos and Pereira, 1993; Holtz-Eakin, 1994; Munnell, 1992). The rates of return on investments implied by studies of this type are sometimes implausibly high (Gramlich, 1994). Studies that correct for serial autocorrelation in the residuals and non-stationarity in the data show ambiguous estimation results (Hulten and Schwab, 1993;

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Tatom, 1993). In general, the results of macroeconomic studies are hard to interpret, because specific investment projects or types of investments are not discerned.

In 1964, Fogel published his work on the growth impact of new railway networks in the United States in the nineteenth century. By carefully constructing an alternative scenario in which the waterway network would have expanded more swiftly, he concludes that the railway impact was rather modest in size compared to total GDP growth. Other cliometric studies focus on the regional growth impact of railways. Constrained by data limitations, these studies use population levels as a proxy of economic activity. Atack et al. (2008, 2009) show that annual population growth in U.S. counties increased 0.41 percentage points between 1850 and 1860 due to the presence of one or more railway lines in a county. Beeson et al. (2001) perform the same regression for the Midwest counties during the period 1840 – 1990 and find an additional annual population growth of 0.12 percentage points. In both studies the railway effect was small compared to overall population growth. Schwartz and Gregory (2008) estimate the same relationship for England and Wales by applying a weighted regression analysis. Their estimation results show that a high rail density reduced population decline in rural areas during the 1870s.

There is little historical research on the consequences of transport improvements on economic growth in the Netherlands. Groote et al. (1999) analyse the relation between total infrastructure investments and GDP growth in the nineteenth century. They conclude that infrastructure investments had a positive influence on growth. However, its influence was temporary and died out after 12 years. Groote et al. do not distinguish between different types of investments (buildings, machines, transport infrastructure) or between locations within the Netherlands. Rietveld and Bruinsma (1998), on the other hand, use data on the number of direct railway lines that connected a city with other municipalities to explain the population growth of the 44 biggest cities in the Netherlands. For the period 1840 – 1890 they find a positive but modest relation. Groote and Tassenaar (2007) examine the impact of the railway network on population growth in two provinces for the period 1820 – 1915. Again the estimation results show a rather small effect. For every kilometer a village centroid was located away from a train station, the population level declined by 19 persons.

With the exception of the work of Fogel, the impact of transport infrastructure on productivity or growth in the studies surveyed above is modeled in a rather crude way. In the case of macroeconomic studies, infrastructure is measured in financial terms (investment sums). In the other studies total length of a network, distance to a station, or being connected to a network is the way the railway network is modeled. This is certainly more refined than in the macroeconomic approach, but there are two main limitations. First, it does not take into account multimodality. Second, network structures are not accounted for. In this paper we use the accessibility concept based upon shortest path calculations over a multi-modal transport network to refine the analysis of infrastructure impacts on growth.

The remaining of this paper is structured as follows. In section 2, we introduce the data set and present the accessibility indicator. Section 3 covers some descriptive statistics and section 4 presents the econometric model. In section 5, we focus on the regression results. Finally, section 6 discusses the results.

2. Data and accessibility

Since regional data on economic growth are lacking for the nineteenth century, we use municipal population growth as a proxy. We obtained data on municipal population levels for 1840, 1849, 1859, 1869, 1879, 1889, 1899, 1909, 1920 and 1930 from the Netherlands population census (CBS, 2009). By imposing the municipality structure of 1930 on previous observations, we made the datasets comparable. Corrections were made for municipality mergers, annexations, divisions and changing municipality borders. Furthermore, we deleted potential errors in the dataset. Those errors concerned growth outliers above four percent per year for which no plausible explanation could be detected in the history of the municipality and that temporarily broke a visible trend. However, most growth outliers could be explained by economic pull factors. For example, in the middle of the nineteenth century, migrants moved to flourishing peat regions in the East of the country. And during the period of industrialization, starting around 1890, industrializing regions attracted many people. The South, in particular, was faced with high migration numbers due to its growing mining industry. In total, the dataset contains 1076 municipalities.

To analyze the infrastructure impacts on growth, we construct an accessibility indicator following a simple gravity approach (Rietveld and Bruinsma, 1998):

$$\mathrm{ACC}_{i,t} = \frac{\mathrm{POP}_{i,t}}{\mathrm{T}_{ii,t}} + \sum_{j \neq i} \frac{\mathrm{POP}_{j,t}}{\mathrm{T}_{ij,t}} \qquad (1)$$

Here, $\mathrm{ACC}_{i,t}$ denotes the accessibility of municipality i, $\mathrm{POP}_{i,t}$ indicates the population level, $\mathrm{T}_{ii,t}$ represents the average internal travel time and $\mathrm{T}_{ij,t}$ stands for the lowest travel time between municipalities i and j. This accessibility indicator can be understood as the weighted number of people that can be reached from the centroid of one municipality.

The first part of equation (1) represents the internal accessibility component. It divides the population level of municipality i by its average internal travel time. The average internal travel time is calculated as follows:

$$\mathrm{T}_{ii,t} = \left(\frac{\sqrt{\mathrm{A}_i/\pi}}{2} \right) / s \qquad (2)$$

Here, A_i reflects the surface area of municipality i and s equals the average internal travel speed. Between brackets we calculate the average internal distance in line with the work of Rich (1980). By dividing the average internal travel distance by the average internal travel speed, we obtain the average internal travel time. We have set the average internal travel speed parameter slightly above walking speed at 6 kilometers per hour.

The second component of the accessibility indicator reflects how accessible municipality i is to all other municipalities by dividing their population levels by the shortest travel time between municipality i and j. We calculated the shortest travel time over an integrated multi-modal transport network constructed in ArcGIS and GeoDMS software. This transport network takes into account opening and closing dates of railway lines and stations (Veenendaal, 2004; Stationsweb 2009). Apart from transport over rail, the network allows for transport over roads. We simulated road infrastructure by drawing ten “as the crow flies“ lines from every node to its ten nearest nodes. We expect that “as the crow flies” lines represent a good approximation of the road structure present at the time. The municipality structure was rather dense so that our road specification does not impose large detours. Furthermore, it is plausible to assume that many (un)paved roads made only small detours towards adjacent towns and municipalities. By defining both municipality centroids and train stations as nodes, we integrated the road and the rail networks. Additionally, we added some roads to the network to capture evidently important missing links that did not satisfy the before mentioned criteria. We imposed average speed levels of 30 and 6 kilometers per hour for rail and road transport respectively. Finally, we calculated shortest travel times from all municipalities to all municipalities over the multimodal transport network for every census year since 1840 by solving a shortest path algorithm.

In our model, we explain local population growth by relative accessibility. We suspect that not the level of accessibility as such, but the relative level of accessibility matters in explaining the growth contribution of railway infrastructure. Among other things, people base their location decisions on the level of accessibility of one municipality in comparison to the average. The relative accessibility level, $\mathrm{RACC}_{i,t}$, is calculated by dividing the accessibility indicator (1) by the population weighted average accessibility level of all municipalities in the concerning period:

$$\mathrm{RACC}_{i,t} = \left(\frac{\mathrm{ACC}_{i,t}}{\overline{\mathrm{ACC}_t}}\right) \quad (3)$$

$$\text{where } \overline{\mathrm{ACC}_t} = \frac{1}{\sum_i \mathrm{POP}_{i,t}} \sum_i \left(\mathrm{POP}_{i,t} * \mathrm{ACC}_{i,t}\right) \quad (4)$$

3. Descriptive statistics

In the Netherlands the first railway lines opened between 1839 and 1849, but after that developments slowed down. The construction of railway lines connecting the harbor cities of Rotterdam and Amsterdam to Germany faced fierce resistance from interest groups. Nevertheless, by 1859 these lines were also opened (Filarski and Mom, 2008). Further private investments were discouraged by the high costs of bridging rivers and the low expected revenues of connecting more isolated Northern regions with the centre. As is illustrated in Table 1 and Figure 1 below, the real growth spurt in railway construction occurred after 1859. In this period, the government decided to intervene in the finance and construction of railway lines. The length of the railway network increased eightfold from around 320 kilometers in 1859 to around 2,500 kilometers in 1889. In later decades, the network kept growing, although at a substantially slower pace. Additional lines mostly served remote local markets. By 1930 the length of the railway network reached its highest level: 3,233 kilometers. During the period 1849 - 1930, the train station density increased from one station per 5.4 kilometer of railway in the first decades to one station per 3 kilometers at the end of the period. This increase partly reflects the nature of the local railway lines opened in the later decades.

Table 1 Summary Statistics

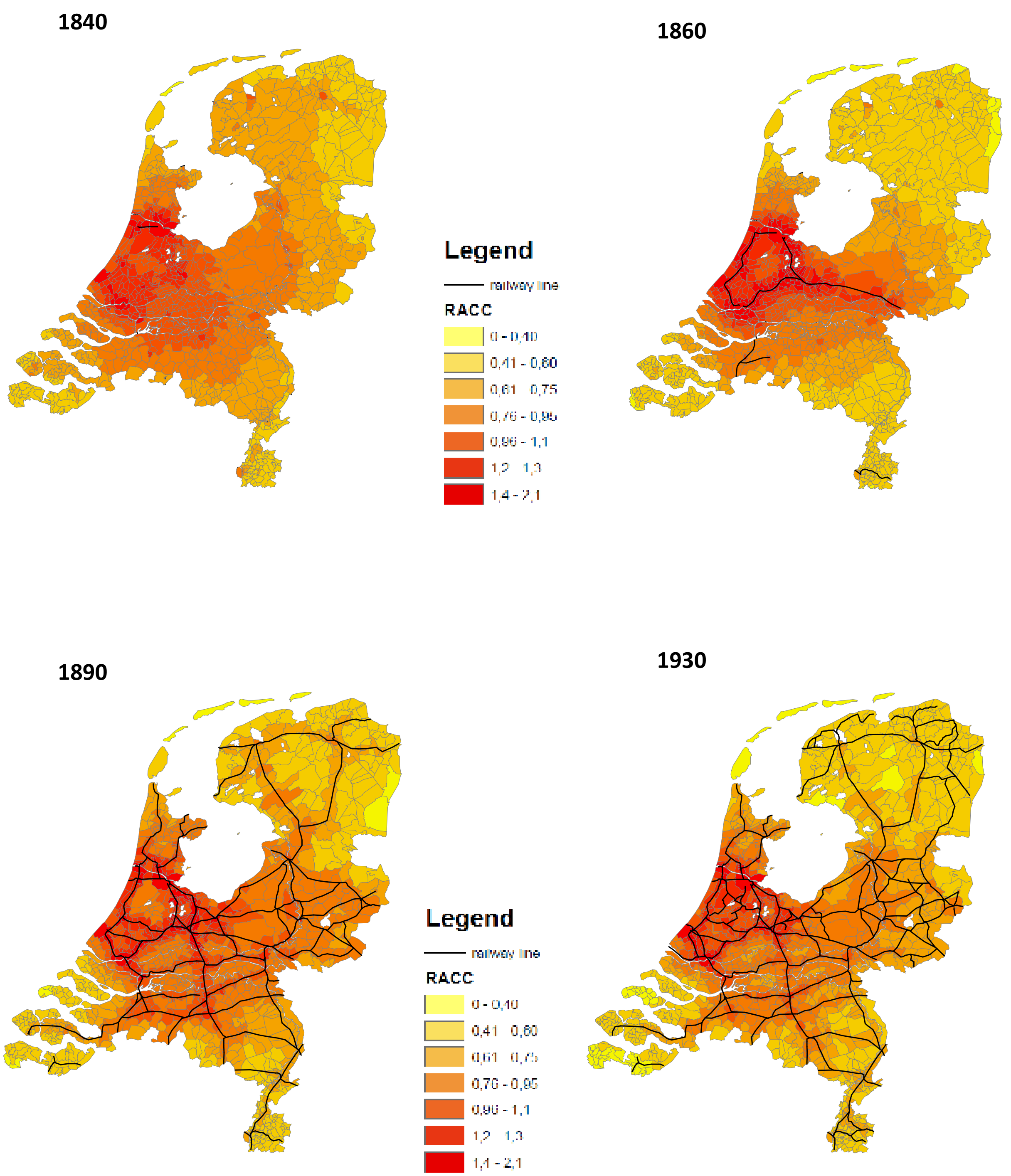
Levels	1840	1849	1859	1869	1879	1889	1899	1909	1920	1930
Railway length (km)	14	175	318	1,211	1,705	2,496	2,615	2,909	3,168	3,233
Average accessibility	87	113	128	191	244	323	392	470	570	667
Population (mln)	2.9	3.1	3.3	3.6	4.0	4.5	5.1	5.8	6.9	7.9
Annual change (%)		**40-49**	**50-59**	**60-69**	**70-79**	**80-89**	**90-99**	**00-09**	**10-20**	**21-30**
Railway		32.4	6.2	14.4	3.5	3.9	0.5	1.1	0.1	0.2
Average accessibility		2.9	1.3	4.1	2.5	2.8	2.0	1.8	1.8	1.6
Population		0.7	0.8	0.8	1.1	1.1	1.3	1.4	1.5	1.4
Real GDP		0.9	0.9	2.0	1.5	3.6	1.1	2.0	2.7	4.3

Source: CBS (2009), Maddison (2009)

The accessibility level increased on average by 2.06 percent per year during the period 1840 – 1930. Note that the increase is partly due to network improvements and partly to overall population growth. The table shows that the first factor was dominant until 1889, whereas the second factor started to dominate in the period after 1889. A large share of accessibility improvements took place in the period of government intervention, between 1859 and 1889. In the first decade of that period, annual accessibility growth peaked at 4.1 percent. Growth was highest in the provinces located in the middle of the country, but these regions never fully caught up in terms of population size with the more densely populated provinces in the West. The development of the accessibility indicator also reflects the evolution of the railway network. Whereas the accessibility of provinces in the West grew strongly in the first decades, the accessibility improved relatively faster in the more isolated provinces in the North and South during the period of government intervention after 1859.

Between 1840 and 1930, population levels grew at a fast pace. The total number of people living in the Netherlands increased by a factor 2.8 from almost 2.9 million in 1840 to more than 7.9 million in 1930. This equals an average annual population growth rate of 1.02 percent. The highest average annual growth rate (1.4 percent) was realized in the industrialization decades between 1890 and 1930.

Figure 1 Railway network and relative accessibility improvements, Netherlands, 1840 – 1930



4. Econometric model

To analyze the effects of railway infrastructure on population growth, we estimate an econometric model. This model explains local population growth by the relative level of accessibility. In order to isolate the growth impact of railway infrastructure, we split the relative accessibility indicator up into two components. They reflect urbanization and railway effects, respectively. In our model, we furthermore make a distinction between the growth impact of accessibility levels and accessibility changes. The reason for including accessibility levels is that relatively better accessible municipalities are expected to permanently attract more people in the long run. We also include changes in accessibility because we expect shifts in accessibility to trigger migration in the short run.

We estimate the following fixed effects model:

$$\frac{\Delta \mathrm{POP}_{i,t}}{\mathrm{POP}_{i,t-1}} = \alpha_1 + \alpha_{2,t}\ln \mathrm{POPDENS}_{t-1} + \alpha_{3,t}\mathrm{CT\_RACC}_{i,t-1} + \alpha_{4,t}\mathrm{RAIL\_RACC}_{i,t-1} + \alpha_{5,t}\Delta\mathrm{RAIL\_RACC}_{i,t}$$
$$+\alpha_{6,t}\mathrm{STAT}_{i,t} + \alpha_{7,i} + \alpha_{8,t} + \varepsilon_{i,t} \quad (5)$$

Here, $\mathrm{POP}_{i,t}$ is the population of municipality i at the end of period t. $\mathrm{POPDENS}_t$ equals population density in persons per square kilometer. It is included in order to account for crowding effects and agglomeration effects within a municipality. $\mathrm{CT\_RACC}_{i,t}$, as defined below, is measured as a relative centrality indicator. Changes in this indicator are only caused by changes in the population distribution, and therefore represent urbanization effects based on proximity. $\mathrm{RAIL\_RACC}_{i,t}$ reflects the relative rail accessibility indicator. Changes are only caused by changes in shortest travel times between municipalities due to improvements in the railway network. $\Delta\mathrm{RAIL\_RACC}_{i,t}$ is defined as the change in relative accessibility. The way $\mathrm{CT\_RACC}_{i,t}$, $\mathrm{RAIL\_RACC}_{i,t}$ and $\Delta\mathrm{RAIL\_RACC}_{i,t}$ are constructed is discussed below. The variable $\mathrm{STAT}_{i,t}$ represents a station dummy indicating whether a train station is located in the municipality. We include this variable to test whether the presence of a train station has an additional effect over and above the accessibility effect. The municipality parameters $\alpha_{7,i}$ are related to fixed effects representing unobserved features of municipalities and the period parameters $\alpha_{8,t}$ are related to fixed effects of time periods.

The relative centrality indicator, $\mathrm{CT\_RACC}_{i,t}$, is obtained by calculating a modified accessibility indicator, $\mathrm{CT\_ACC}_{i,t}$, based on constant travel times throughout the period considered. We chose 1830 as the base year since no railway infrastructure was present at the time. We standardize the centrality indicator by making use of $\overline{\mathrm{ACC}_t}$.

$$\mathrm{CT\_ACC}_{i,t} = \frac{\mathrm{POP}_{i,t}}{\mathrm{T}_{ii,1830}} + \sum\nolimits_{j \neq i} \frac{\mathrm{POP}_{j,t}}{\mathrm{T}_{ij,1830}} \quad (6)$$

$$\mathrm{CT\_RACC}_{i,t} = \left(\frac{\mathrm{CT\_ACC}_{i,t}}{\overline{\mathrm{ACC}_t}}\right) \quad (7)$$

Since $\mathrm{CT\_RACC}_{i,t}$ is based on a fixed pedestrian network its development merely reflects changes in relative population size in municipalities of municipalities nearby and further away. It can be interpreted as a centrality measure based on the notion of proximity. Developments in the railway network do not play a role in it.

By taking the difference between $\mathrm{RACC}_{\mathrm{i,t}}$ and $\mathrm{CT\_RACC}_{\mathrm{i,t}}$, the relative rail accessibility indicator, $\mathrm{RAIL\_RACC}_{\mathrm{i,t}}$, is obtained:

$$\mathrm{RAIL\_RACC}_{\mathrm{i,t}} = \mathrm{RACC}_{\mathrm{i,t}} - \mathrm{CT\_RACC}_{\mathrm{i,t}} \qquad (8)$$

Changes in this difference reflect accessibility changes due to improvements in the railway network only. Note that when $\alpha_{3,\mathrm{t}}$ would be equal to $\alpha_{4,\mathrm{t}}$ in equation (5) the population component and the travel time component would be of equal importance in explaining population growth. When $\alpha_{4,\mathrm{t}}$ would be zero, the contribution of railway development to population growth would be absent. $\mathrm{RAIL\_RACC}_{\mathrm{i,t}}$ can thus be interpreted as the contribution of railway lines to the accessibility after that pedestrian based distances and population distributions (reflected by $\mathrm{CT\_RACC}_{\mathrm{i,t}}$) have already been accounted for.

Changes in relative accessibility are calculated by taking the differences of the rail accessibility indicator at the end of the period and its value at the beginning of the period:

$$\Delta\mathrm{RAIL\_RACC}_{\mathrm{i,t}} = \mathrm{RAIL\_RACC}_{\mathrm{i,t}} - \mathrm{RAIL\_RACC}_{\mathrm{i,t-1}} \qquad (9)$$

The parameters of population density, relative accessibility, changes in relative accessibility, and the railway station dummy are time dependent. This allows us to see whether the impact of accessibility changed over time[3].

5. Regression results

For most periods, the regression results in Table 2 show a positive and highly significant relation between the two components of the relative accessibility level and population growth. The coefficients must be interpreted as the additional annual percentage point population growth for every 100 percentage points the municipality was more accessible than the average. The relation between the relative centrality indicator and population growth is significant and positive implying the presence of strong urbanization patterns throughout the period. The relation between the relative rail accessibility indicator and population growth is significant and positive for periods after 1880. Municipalities that were twice as accessible as the average municipality in the period 1880 – 1889, due to their location in the railway network, grew 1 percentage point faster per year in that period. This growth impact increased fourfold to 4.01 percentage points for the last period 1921 – 1930. The impact of the centrality indicator is much larger than that of the rail accessibility indicator. Both accessibility components show a higher positive relationship after 1880 than before. In those later periods industrialization took off in the Netherlands. So, better accessible municipalities benefited relatively more from industrialization than less accessible municipalities. By applying a standard Wald test, we checked whether the coefficients of the two accessibility components are the same over the periods. This hypothesis was rejected. Overall, we conclude that urbanization effects existed throughout the

[3] In order to avoid endogeneity problems, we did not include changes in CT_RACC in the model.

entire period and that municipalities that were better accessible due to their location in the rail network faced higher population growth from 1880 onwards.

Apart from the level of accessibility, also changes in relative accessibility levels might explain differences in growth patterns. Table 2 shows a mixed picture with regard to the significance and the magnitude of this effect. It is only in the decades after 1900 that changes in the accessibility of municipalities had substantial and significant effects on population growth. Note that these were also periods with strong GDP growth.

A possible explanation is that changes in relative accessibility occurring in periods of high economic growth affected population growth more than they did in periods of stagnation. The impact of accessibility changes is often high in periods with high GDP growth rates (Table 1). We tested the possible relation between changes in accessibility and real GDP growth rates by including an interaction variable. We indeed found that the impact of changes in relative accessibility on regional population growth was positively related to real GDP growth. Thus, changes in the railway network tend to have a stronger spatial redistribution effect during periods with high economic growth.

From 1880 onwards, the growth impact of having at least one train station within the municipality borders was statistically significant and positive. Cumulative effects are quite large. Using the regression coefficients, we can compute that municipalities which had at least one train station in 1879 were 16% bigger in 1930 than otherwise comparable municipalities which did not have a railway station. We also ran a regression including the change in the presence of train stations. The individual coefficients of the changes were highly insignificant. It is possible that multicollinearity exists between the station dummies and the rail accessibility variables. However, by calculating the uncentered variance inflation factor, we did not identify multicollinearity. Nevertheless, we regressed our model excluding the station dummies. As would be expected, the estimators of $\mathrm{RAIL\_RACC}_{i,t}$ and $\Delta\mathrm{RAIL\_RACC}_{i,t}$ increased.

Our study finds evidence for convergence in population density. The impact of lagged population density levels on population growth is statistically significant and negative for all periods. So during the period 1840 – 1930, municipalities with lower population density caught up with bigger municipalities. Although not directly comparable, the sign of the coefficients is in line with the empirical growth literature on β-convergence (Sala-i-Martin, 1996). A standard Wald test shows that the impact differs between periods.

The coefficients of the fixed municipality effects range between -6.56 and 5.21. Municipalities with the lowest fixed effect coefficients are found in the best accessible provinces (Utrecht, Zuid-Holland and Noord-Holland). Southern municipalities are overrepresented in the highest range. The main reason for this is the increasing activity in the local mining industry. Among the municipalities with the lowest fixed effect coefficients are also the biggest four municipalities: Amsterdam (-6.56), Rotterdam (-5.89), Utrecht (-3.27) and The Hague (-2.46). The fixed time effects reflect the deviations from the mean population growth over the entire period. From 1879 to 1930, we find large negative and mostly statistically significant effects. As shown in Table 3, these negative effects are more than compensated by other effects. As a result the actual growth is high in this period.

Table 2 Regression results

(Dependent variable: annual average population growth per period in percentages, n = 9658, R-squared = 0.34)

Variables		Coefficient	(standard error)
Constant		0.17	(0.48)
LnPOPDENS(t-1)	1840 – 1849	-1.34***	(0.08)
	1850 – 1859	-1.23***	(0.09)
	1860 – 1869	-1.33***	(0.09)
	1870 – 1879	-1.17***	(0.09)
	1880 – 1889	-1.00***	(0.09)
	1890 – 1899	-0.99***	(0.09)
	1900 – 1909	-1.07***	(0.08)
	1910 – 1920	-1.15***	(0.08)
	1921 – 1930	-1.18***	(0.08)
CT_RACC(t-1)	1840 – 1849	8.42***	(0.55)
	1850 – 1859	10.57***	(0.66)
	1860 – 1869	11.58***	(0.70)
	1870 – 1879	15.76***	(0.94)
	1880 – 1889	17.03***	(1.03)
	1890 – 1899	16.88***	(1.13)
	1900 – 1909	16.61***	(1.13)
	1910 – 1920	15.21***	(1.10)
	1921 – 1930	16.88***	(1.11)
RAIL_RACC(t-1)	1840 – 1849	0.28	(1.16)
	1850 – 1859	-0.08	(0.33)
	1860 – 1869	0.13	(0.33)
	1870 – 1879	-0.28	(0.30)
	1880 – 1889	1.00***	(0.31)
	1890 – 1899	1.33***	(0.32)
	1900 – 1909	1.96***	(0.33)
	1910 – 1920	3.08***	(0.34)
	1921 – 1930	4.01***	(0.34)
ΔRAIL_RACC(t)	1840 – 1849	0.42	(0.36)
	1850 – 1859	0.87*	(0.51)
	1860 – 1869	-0.58*	(0.32)
	1870 – 1879	-0.93**	(0.44)
	1880 – 1889	0.94**	(0.41)
	1890 – 1899	0.32	(0.93)
	1900 – 1909	2.27**	(1.08)
	1910 – 1920	5.27***	(0.81)
	1921 – 1930	8.94***	(2.55)
STAT(t)	1840 – 1849	0.35	(0.26)
	1850 – 1859	0.08	(0.19)
	1860 – 1869	0.29***	(0.11)
	1870 – 1879	0.16	(0.10)
	1880 – 1889	0.33***	(0.09)
	1890 – 1899	0.37***	(0.09)
	1900 – 1909	0.31***	(0.09)
	1910 – 1920	0.16*	(0.08)
	1921 – 1930	0.30***	(0.08)
Fixed time effects (dummy)	1850 – 1859	-0.89***	(0.25)
	1860 – 1869	-0.50*	(0.26)
	1870 – 1879	-0.84***	(0.26)
	1880 – 1889	-2.11***	(0.25)
	1890 – 1899	-1.25***	(0.25)
	1900 – 1909	-0.26	(0.25)
	1910 – 1920	0.64**	(0.25)
	1921 – 1930	0.06	(0.25)

Standard errors in parentheses *** 1% significancy, ** 5% significancy, * 10% significancy

Table 3 also shows the growth contribution of average changes in the explanatory variables for different periods. In order to calculate these growth contributions, we took unweighted averages for most variables, except for the station dummy which we weighted by population levels. As would be expected, the model predicts population growth rates well for the average municipality. For individual municipalities we expect to find higher residual values since the part of population growth explained by the model (R-squared) is only 34 percent. That is indeed what we found when we decomposed the growth contribution of our regressors. In general, the effect of the rail accessibility variables is relatively small compared to the impact of other explanatory variables. Urbanization and crowding effects seem to dominate, even though the influence of rail accessibility is increasing in the later periods of industrialization.

Table 3 Decomposition of predicted growth for an average municipality, 1840-1930

	Explanatory variable									
	Const.	**LnPOP DENS (t-1)**	**CT_ RACC (t-1)**	**RAIL_ RACC (t-1)**	**Δ_RAIL_ RACC (t)**	**STAT (t-1)**	**Fixed time Effects**	**Fixed municipal effects**	**Predicted growth**	**Actual growth**
1840 - 1849	0.17	-5.88	6.91	0.00	0.05	0.01		-0.48	0.77	**0.77**
1850 - 1859	0.17	-5.50	7.26	-0.01	0.03	0.00	-0.89	-0.48	0.59	**0.59**
1860 - 1869	0.17	-6.00	7.52	0.02	-0.12	0.04	-0.50	-0.48	0.66	**0.66**
1870 - 1879	0.17	-5.38	7.47	-0.10	-0.05	0.03	-0.84	-0.48	0.82	**0.82**
1880 - 1889	0.17	-4.67	7.08	0.41	0.03	0.10	-2.11	-0.48	0.52	**0.52**
1890 - 1899	0.17	-4.65	6.00	0.60	-0.00	0.12	-1.25	-0.48	0.51	**0.51**
1900 - 1909	0.17	-5.11	5.55	0.87	-0.01	0.11	-0.26	-0.48	0.84	**0.84**
1910 - 1920	0.17	-5.60	4.88	1.36	0.03	0.06	0.64	-0.48	1.05	**1.04**
1921 - 1930	0.17	-5.88	5.25	1.79	-0.05	0.12	0.06	-0.48	0.98	**0.98**

6. Conclusion and discussion

The emergence of the railway network in the period 1840 – 1930 boosted regional accessibility levels in the Netherlands considerably. In this study, we investigated the population growth impact of these accessibility improvements by constructing a relative rail accessibility indicator. We have shown that relative rail accessibility levels contributed to population growth over a prolonged period of time. A significant and positive effect was found between 1880 and 1930 when industrialization took off in the Netherlands. The growth impact increased over that period by a factor 4, from 1 percentage point in the period 1880 - 1889 to 4.01 percentage points between 1920 and 1930. Also the impact of changes in rail accessibility on population growth is significant and positive after 1900. Before 1900, the growth impact of changes in relative accessibility differs between periods. The overall impact of rail accessibility on local population growth is small compared to the growth impact of other explanatory variables. Especially, urbanization and crowding effects dominate the model. This finding confirms earlier work done in the Netherlands.

There is still substantial scope for further research on this theme. Possible extensions include the use of data on trip making in order to check whether the adopted value of the distance decay parameter (-1) is appropriate. Also, the multimodal character of accessibility can be further improved by adding inland water transport which was an important alternative during the period considered. Further, speed differences may be treated in a more refined way. Another extension of the analysis concerns addressing the possible presence of endogeneity due to reversed causality from population growth on railway expansions. Finally, for a relatively small country such as the Netherlands also the impact of international accessibility owing to developments on border regions may be of interest.

	Per	Cons.	LnPOP DENS (t-1)	CT_ RACC	RAIL_ RACC	d_RAIL_ RACC	Stat	Fixed Time effects	Mun effects	Pred. growth	Real growth
Amsterdam	1849	0.17	-9.67	16.23	0.03	0.18	0.35	0.00	-6.56	0.72	0.64
Amsterdam	1859	0.17	-8.97	17.01	-0.05	0.00	0.08	-0.89	-6.56	0.80	0.74
Amsterdam	1869	0.17	-9.75	17.64	0.07	-0.05	0.29	-0.50	-6.56	1.32	0.94
Amsterdam	1879	0.17	-8.72	17.69	-0.17	0.06	0.16	-0.84	-6.56	1.79	1.88
Amsterdam	1889	0.17	-7.64	17.51	0.56	0.09	0.33	-2.11	-6.56	2.34	2.57
Amsterdam	1899	0.17	-7.77	16.11	0.87	-0.01	0.37	-1.25	-6.56	1.94	2.24
Amsterdam	1909	0.17	-8.69	15.76	1.23	-0.01	0.31	-0.26	-6.56	1.96	1.12
Amsterdam	1920	0.17	-9.48	13.63	1.92	0.01	0.16	0.64	-6.56	0.48	1.32
Amsterdam	1930	0.17	-9.90	14.55	2.51	0.05	0.30	0.06	-6.56	1.18	1.08

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