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Introducing Railway Time in the Balkans: Economic effects of railway construction in Southeast Europe and beyond since the early 19th century until present days

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Global Development Network Southeast Europe
The wiiw Balkan Observatory

Introducing Railway Time in the Balkans

Economic effects of railway construction in Southeast Europe and beyond since the early 19^{th} century until present days *

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Working Paper

Abstract

In this paper we analyse the economic effects of railway infrastructure at the national level for European countries as well as at the local level for Southeast European cities based on a novel railway database capturing decades of the 19^{th} century up to the early 21^{th} century. A panel fixed effects regression analysis at the country level indicates a positive economic impact emanating from railway infrastructure, whereby the effect appears to be even stronger for less developed Southeast European countries. In addition, a linear spatially augmented multilevel model at the city level sheds light on the positive effects resulting from railway infrastructure on urban development. Its positive spillover effects occur within countries as well as across borders.

Keywords: Railway, infrastructure, Balkans, Southeast Europe, backwardness, urban development, economic development, railway accessibility, infrastructural spillovers, multilevel model, historical analysis.
JEL-codes: L92, N13, N14, N73, N74, N93, N94, O18, O47, R11, R41

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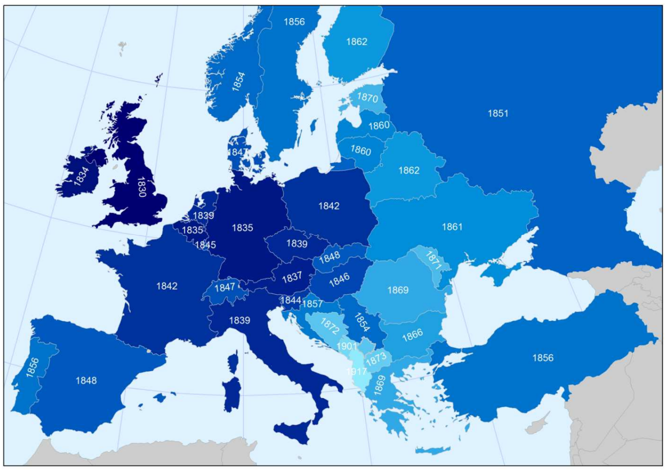
1 Introduction

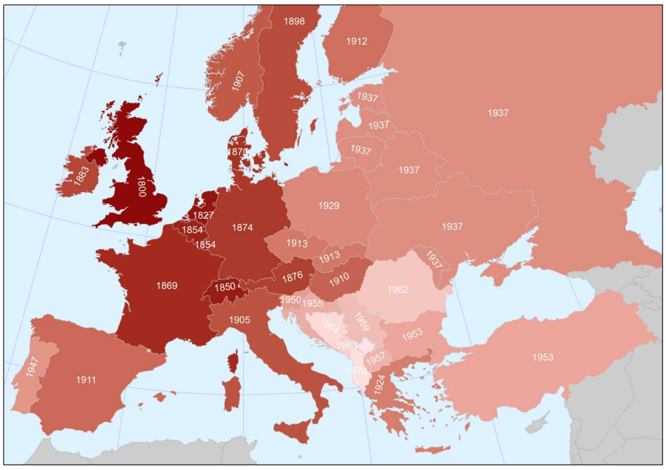
In this paper we examine the economic effects of the (historical) construction of railway infrastructure and its accessibility in Southeast Europe and beyond. Our approach is twofold. First, we analyse the impact of railway length on GDP per capita growth by using panel fixed effects regression models and data from 1830 to 2010 for 33 European countries. In addition, a linear spatially augmented multilevel regression model is applied to investigate the direct and spillover effects of railway infrastructure and its accessibility on population growth and thus urban development by employing city data from 1850 up to 2000 for 12 Balkan countries. Here, population growth at the city level serves as a proxy for regional economic development. In order to conduct these two steps, we use historical GDP data from the Maddison database as well as novel railway and city population data from the Historical Geographical Information System for Europe (HGISE) for every decade (i.e. ten year intervals). To ensure comparability, we apply current country borders along the entire time span. We are aware that the specific country borders varied over time, but the applied current country borders reflect in many cases territorial sub-divisions of historical empires and are therefore connected to a set of long-lasting institutions.

In general, our results point to a significantly positive impact of railway infrastructure on GDP per capita growth of (Southeast) European countries and furthermore on population growth of cities and consequently on urban development in the Balkans. In the context of the country regressions we identify a statistically causal impact of railway infrastructure on GDP per capita growth. However, this impact seems to have changed in the 20^{th} century compared to the 19^{th} century. Moreover, we find evidence for a stronger impact in the underdeveloped Balkan countries and less impact for more developed countries. The results of the city regressions highlight a positive direct effect of railway accessibility on city's population growth and thus urban development. Thereby, we find evidence for the essential role of railway accessibility especially in city centres. Moreover, we provide evidence for (indirect) spillover effects of railway accessibility, which seem to exceed the direct effect and occur between cities within a county and as well across countries.
With this paper we contribute to the literature on infrastructure, particularly on railways, and its role for economic development and urbanisation. Our approach enables us to compare data across different eras and capture potential long term effects. To our knowledge so far nobody has analysed the economic role of railway tracks for Southeast Europe based on such a long historical perspective.

The link between infrastructure, particularly railway, and economic development has been on stage of economic discussion for a long period of time (for example Aschauer, 1989; Fogel, 1994). Infrastructure is a crucial input for any economy's production function (see Estache and Fay, 2007). Going back in history, the arrival of the railway has heralded the transportation revolution, which was related to the first globalisation and the Second Industrial Revolution, i.e. Technological Revolution. The map in the upper panel of Figure 1 displays the year of the construction of the first railway line across European countries. The first railway track was opened in September 1830 between Liverpool and Manchester in the United Kingdom. From there on, railway lines continuously spread from Europe's Northwest to the Southeast.
The pattern of economic development in Europe is quite similar. The map in the lower panel of Figure 1 illustrates the years when the respective country surpassed 2000 USD in GDP per capita (1990 Int. GK$). Again, the United Kingdom has started the development, followed by Central European countries and lastly by Southern and Eastern European countries.
In principal, the two maps demonstrate a similar geographical dispersion, albeit railways' geographical diffusion was faster. Based on these historical facts, it appears that there is a correlation between railway construction and economic development of countries, although the direction of a potential causal impact remains unclear.

Figure 1: Year of construction of first railway line (above), year of surpassing 2000 USD in GDP per capita (1990 Int. GK$) (below)





Note: Railway: Kosovo 1874. GDP per capita: Interpolation for Ireland; extrapolation for Slovenia; Kosovo 2002 estimate based on wiiw data; Czecho slovak observation for Cezch and Slovak Republic; Belgian observation for Luxembourg, Soviet observation for Russia, Estonia, Latvia, Lithuania, Belarus, Ukraine and Moldova.

Source: Wikipedia, Wikimedia, FDV, The Maddison-Project (2013), wiiw, own estimates.

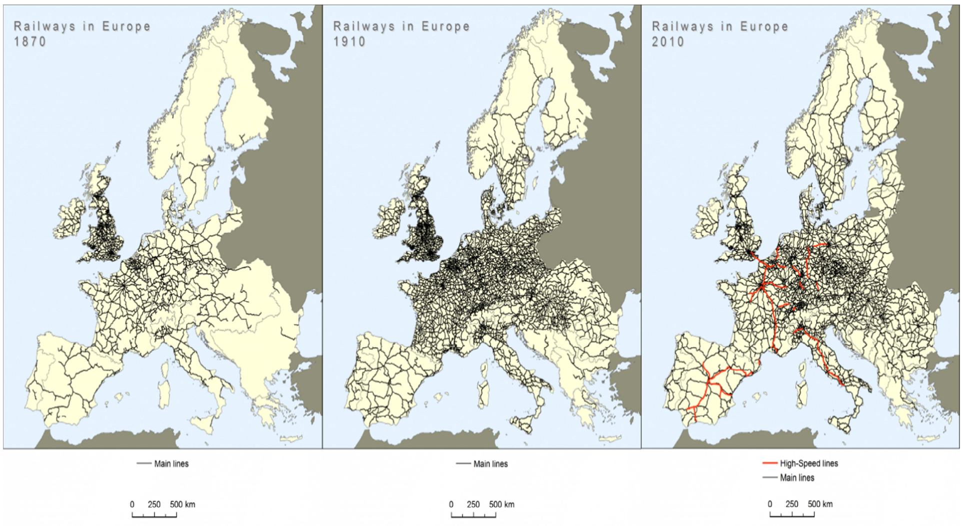
Both maps indicate that Southeast European countries have somewhat lagged behind all the other European countries. Up until now, Southeast Europe has even been characterised by an economic and an infrastructural backwardness (see Holzner, Stehrer, and Vidovic, 2015). One main cause of the economic backwardness of this region is not only the delayed, but also the unaccomplished industrialization. Southeast Europe has entered the stage of de-industrialisation before it even completed industrialisation (see Babanassis, 2003). Already back in 1943 Rosenstein-Rodan advocated a *'big push'* of coordinated infrastructure investments as a trigger for overall economic development, in order to solve the *'problems of industrialisation of Eastern and South-eastern Europ'*. However, this big push never occurred and infrastructure bottlenecks can still be identified which hints at substantial investment needs, *inter alia* in railways (see Holzner, Stehrer, and Vidovic, 2015). This can be also observed when looking at the development of the railway system across Europe as illustrated in the maps of Figure 2. In the last 100 years there has been a rather weak development of the railway infrastructure in Southeast Europe.
In addition to the general role of infrastructure for aggregate production, economic research addresses as well the potential impact on regional economic growth and urban growth. The presence of railways might have essential implications for improving accessibility, enhancing development, and fostering population agglomeration and urban growth at the regional level. Accessibility to regional markets promotes regional economic development, by interactions of agglomeration forces, economies of scale and lower transportation costs (see Ahlfeldt and Feddersen, 2015). Following these arguments, Figure 3 contrasts the average population growth of cities with and without an access to railways in the inner centre of the city across Balkan countries between 1850 and 2000.

In most Balkan countries cities with railway access have revealed, on average, a higher population growth compared to cities without any access to railways. With the exceptions of Romania, Serbia and Turkey, railway accessibility seems to be linked to a higher urban growth rate and thus urban economic development at a first glance. Based on these descriptive relationships, we derive two research questions. *'What is the impact of a higher railway mileage on economic growth, in particular for less developed (i.e. Southeast European) countries?'* Furthermore, we derive a second research question to address the regional impact of railway accessibility on urban growth (i.e. our regional economic development proxy). *'What are the direct and indirect effects of railway accessibility on population growth of Balkan cities?'* In this regard, direct effects for cities occur due to a direct access to the railway system, whereas indirect effects are spillover effects resulting from the access to the railway system of neighbouring cities.

2 Literature Review

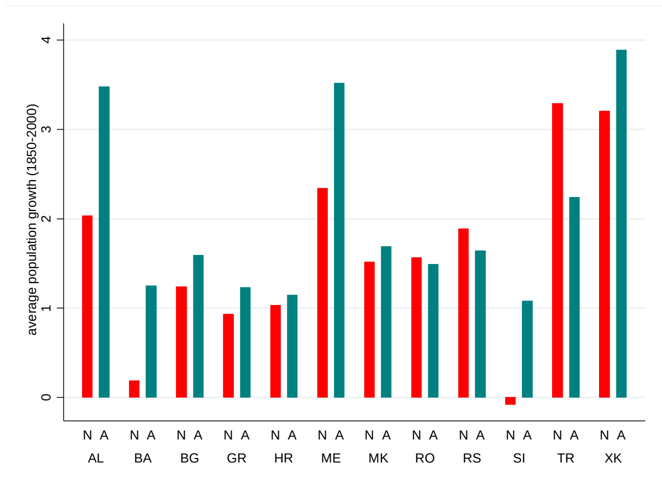
Transport infrastructure including railway networks can reduce *inter alia* the costs of the production of goods and services. Markets can be linked together and can be enlarged which might result in a better division of labour and higher productivity (see for example Murphy, Shleifer, and Vishny, 1988). Due to spillover effects the entire economy can benefit from investment in infrastructure. The impact of infrastructure on the reduction of transaction costs is also emphasised by Aghion and Schankerman (1999), although they are additionally focused on the effects of intensified competition, an enhanced market selection of efficient firms and an incentive for the restructuring of as well as the entry in new markets. Atack, Haines, and Margo (2008) additionally point to productivity increases of firms.
Moreover, a highly diffused railway network seems to have an impact on labour mobility (see for example Collins, 1999) and on the deepening and efficiency of capital markets (see for example Bogart, 2005). In addition to the impact on aggregate income as well as its growth rate, there might also be an influence on income inequality and poverty reduction. As discussed by Calderon and Serven (2014), infrastructure improves the access to productive opportunities, can enhance human capital and increases the potential for the integration of low-income groups into social and economic life.

Figure 2: Railway network density in Europe 1870, 1910 and 2010



Source: HGISE (2015).

Figure 3: Average population growth (1850-2000) of cities across Balkan countries by railway accessibility



Note: City data represents an unbalanced panel dataset. Average population growth of cities refers to varying time periods. *'N'* regards no access to railway, whereas *'A'* captures cities with an access. Cities belong to group *'A'* if they disclose railway accessibility at any time during the respective period. Country codes: Albania (AL), Bosnia-Herzegovina (BA), Bulgaria (BG), Greece (GR), Croatia (HR), Montenegro (ME), Macedonia (MK), Romania (RO), Serbia (RS), Slovenia (SI), European part of Turkey (TR) and Kosovo (XK).
Source: HGISE (2015), own calculations.

Apart from these, the construction of railway transport systems additionally may be linked with urban population growth. Railway construction might be related to economic improvements, which result in higher income and subsequently in population growth. In addition to new economic opportunities, railways might lead to improved mobility and migration (see for example Schwartz, Gregory, and Thevenin, 2011). Thus, railway networks might foster population growth in cities (see Atack, Bateman, Haines, and Margo, 2010). Higher levels of accessibility might lower the costs of interactions and increase the attractiveness of a location. Kotavaara, Pukkinen, Antikainen, and Rusanen (2014) have explored the characteristics of Finish population dynamics between 2003 and 2009 by using a non-linear multiple regression, generalised additive model. They have found evidence that road accessibility mainly benefited centre areas and that the proximity to airports seemed to attract population. However, regional development appears to be unaffected by railway accessibility. Kotavaara, Pukkinen, Antikainen, and Rusanen (2014) have used a gravity-based potential accessibility measure. By contrast, da Silveira, Alves, Lima, Alcantara, and Puig (2011) have examined the relationship between local population and railway accessibility in Portugal from 1801 to 1930 by using data from censuses. Their results suggest that railway access promoted the increase in population concentration in areas with this infrastructure. Railway accessibility fostered the growth of pre-existing urban centres as well as the creation of new ones. Moreover, it encouraged migration into towns. In this framework railway accessibility was measured by the presence of a railway station within a radius of five kilometres. Likewise, Koopmans, Rietveld, and Huijg (2012) have provided evidence for the positive impact of railway on municipal population growth in the Netherlands between 1840 and 1930 using census data and applying a fixed effects model. They have generated a relative accessibility indicator, where accessibility is compared to the average level of accessibility based on a gravity approach. In addition Ahlfeldt and Feddersen (2015) have explored the regional impact of the introduction of the German high speed rail track connecting Cologne and Frankfurt and therefore the increased accessibility on sustainable economic development by using NUTS3 data from 1992 to 2006. Using a non-parametric identification strategy, their results suggest a partly permanent positive regional economic effect due to the increase in market access. Furthermore, Redding and Sturm (2008) have provided evidence for a causal relationship between market access and the geographical distribution of economic activity and economic development by using a balanced panel of West German cities covering 1919 to 2002. By contrast, Crescenzi and Rodríguez-Pose (2012) have investigated the role of regional infrastructure (motorways) for regional growth in the EU 15 by using a combination of NUTS1 and NUTS2 data between 1990 and 2004. The results of a generalised method of moments (GMM) dynamic panel regression imply that the infrastructure endowment is not crucial for regional economic growth. Neither having a good endowment of roads, nor being surrounded by regions characterised by pronounced infrastructure has had a significant impact on regional economic development.

According to Banerjee, Duflo, and Qian (2012) infrastructure investments are not beneficial for economic development in the absences of a strong demand for it. This is particularly relevant for locations along a route connecting major cities. Mojica and Martí-Henneberg (2011) have found evidence that the construction of railway in Spain was hardly driven by demand pressure, whereas it was aimed to link political and administrative capitals. Moreover, Duranton and Turner (2012) outline that roads in the US were built where land and labour were cheap and not where they were necessarily needed. Consequently, the overall economic impact of railway construction might be affected by decisions and reasons where to build the railway.

Aghion, Besely, Browne, Caselli, Lambert, Lomax, Pissarides, Stern, and Reenen (2013) describe the impact of infrastructure on economic development in a more analytical way. Infrastructure may affect economic development directly as an input in the production process (see also Arrow and Kurz, 2013; Barro, 1990) and indirectly by raising total factor productivity due to reduced transaction costs (for a discussion see for example Hulten and Schwab, 1997). Furthermore, Aghion, Besely, Browne, Caselli, Lambert, Lomax, Pissarides, Stern, and Reenen (2013) point to some sort of spillover effects emanating from infrastructure investments as well. In this regard, infrastructure investments are complementary to other investments. This is also addressed by Arrow and Kurz (2013), as they assume a complementary effect on non-infrastructure inputs.

Canning and Pedroni (2008) explore the long run impact of infrastructure on per capita income. By using panel data between 1950 and 1992 and applying an error correction model as well as a panel cointegration technique, they have found evidence for long-run growth effects. Donaldson and Hornbeck (2013) calculate country to country transportation costs and analyse country-level variation in market access for the US based on a geographic information system (GIS) network database. Their counterfactual scenarios show that without railways in 1890 there would have been annual economic losses equal to 3.40% of GNP. Furthermore, Fernald (1999) highlights that infrastructure investments offer *'a one-time boost to the level of productivity rather than a path to continuing rapid growth in productivity.'* Under his network argument, infrastructure investments might be very productive at the beginning of the construction, but the impact of further infrastructure construction diminishes continuously. These diminishing returns to infrastructure are also emphasized by Estache and Garsous (2012). They argue that the impact of infrastructure depends on the stage of development of countries, the time period over which the impact is assessed and the type of infrastructure. The more developed a country is, the higher the infrastructure stocks and the lower its returns, given that it is not related to a major technological improvement. Canning and Bennathan (2000) have found empirical evidence for nonlinearity and pointed out that the highest rates of return on infrastructure investments (electricity, paved roads) is yielded when a network effect is sufficiently developed but not completely achieved. Thereby, infrastructure is found to be strongly complementary with physical and human capital. They have estimated a Cobb-Douglas as well as a translog production function with infrastructure in low income and high income countries between 1960 and 1990 by considering fixed effects and short run dynamics for modelling the cointegrated production function, principally based on data from Penn World Tables. Both types of infrastructure have revealed rapidly diminishing returns.

Sugolov, Dodonov, and Hirschhausen (2003) have examined the relation between infrastructure policies and economic development in countries of Eastern Europe and the Commonwealth of Independent States, using data on 15 countries from 1993 to 2000. Their results suggest a positive impact of infrastructure given that a certain threshold of reforms has been exceeded. Furthermore, Holzner, Christie, and Gligorov (2006) have addressed as well this relationship with a focus on countries of Southeast Europe and concluded that investments on infrastructure should lead to an efficient allocation of resources.

Although we have discussed the impact of railway construction on economic development, the causal effect is not that clear as it seems. This is related to the question whether the effect of railway investments is assumed to be exogenous or endogenous. Fishlow (1965) argues *'[...] whether railroads first set in motion the forces culminating in the economic development of the decade, or whether arising in response to profitable situations, they played a more passive role.'* Felis Rota (2014) has applied vector autoregressive (VAR) models to analyse simultaneous effects between railway construction and real GDP. The results have pointed into both directions. Atack, Bateman, Haines, and Margo (2010) have dealt with the endogeneity issue concerning railways and have used instrumental variables (IV) to control for simultaneity. Caruana-Galizia and Martí-Henneberg (2013) have also applied an IV estimation approach to analyse the relationship between railways and real income levels for different European regions from 1870 up to 1910. Using railway data from the Historical Geographical Information System for Europe (HGISE) they have found a positive effect due to railway infrastructure stocks, but a negative effect emanating from railway infrastructure of neighbouring regions, whereby the positive exceeds the negative impact. Although the simultaneity issue is likely to cause an upward bias in the estimated infrastructure effects, Fernald (1999) argues that this bias is not large. Moreover, Canning and Pedroni (2008) claim that feedback effects of economic development on infrastructure may only occur in the short run. In accordance with the results of Canning and Pedroni (2008), Calderon and Serven (2004) have found a robust positive growth effect through higher infrastructure stocks (*inter alia* transport stocks). They have modelled simple growth equations and included infrastructure quantity and quality as further regressors by using five-years averaged panel data for over 100 countries from 1960 up to 2000. To account for simultaneity, they have used a GMM estimator based on internal and external instruments.

Aghion, Besely, Browne, Caselli, Lambert, Lomax, Pissarides, Stern, and Reenen (2013) underline the importance of infrastructure investments and the related role of governments. *'Investments in infrastructure, such as transport, [...] are essential inputs into economic growth. [...] They also tend to be large-scale and long-term, requiring high levels of coordination to maximise the wider benefits that they offer. This makes it inevitable that governments will play a vital role in planning, delivering, and (to some extent) financing such projects.'* In accordance with this argument, much earlier Rosenstein-Rodan (1943) and Murphy, Shleifer, and Vishny (1988) have already promoted infrastructure projects as a potentially important component of a *'big push'* to foster economic development. Murphy, Shleifer, and Vishny (1988) argued that infrastructure investments should be coordinated by governments, due to spillover effects. More recently, the *IMF* (see Abiad, Almansour, Furceri, Granados, and Topalova, 2014) in its *'World Economic Outlook'* proposed an infrastructure push for countries with infrastructure needs. Concerning this, Abiad, Almansour, Furceri, Granados, and Topalova (2014) identifies infrastructure bottlenecks, especially in emerging markets and developing economies. Even in case of debt-financed infrastructure investments, Abiad, Almansour, Furceri, Granados, and Topalova (2014) highlights positive short- and long-term output effects.

In sum, the literature seems to provide scarce results regarding the effects of infrastructure investments on economic development in Southeast European countries at regional as well as national level. Thus, the examination of our defined research questions addresses this gap and will provide an intuition on infrastructure investment potentials. A unique historical railway dataset will allow us to do novel research on this topic.

3 Data

The data used in the present paper can be divided into two domains. We use data at the national level for comparing developments in European countries. At the same time, we use local data for a detailed regional analysis focused on Balkan cities.

First, we discuss the data at the national level. Our railway data consists of series containing information about the evolution of the network of Europe for the decades between 1830 and 2010. It is presented in a vector GIS format. This information was digitised using different categories of thematic maps. Unfortunately, there does not exist a precise railway map series for Europe for the period 1830-2010. As a result there is a lack of uniformity between the sources we used and this makes it challenging to undertake comparative studies of the evolution of the network for the whole of Europe (see Morillas-Torné, 2012). In our case, we used thematic maps of railways as our preferred source as they highlight railway lines. Although these sources are often old editions, some of them aimed at tourists, these maps tend to be accurate and allow us to trace the historical evolution of the railway network. The main sources of information that we used for this project were the Digital Chart of the World, which is a vector data model at a scale of 1:1,000,000, which was created by the *'US Defense Mapping Agency'* (DMA) and published by the *'Environmental Systems Research Institute, Inc.'* (ESRI) in 1992. Amongst other features, this contains a layer with the railways in Europe. We used it as a reference for the railway lines of Europe. Second, *'Thomas Cook publishing'* offers a series of railway maps for Europe in which each map shows the lines recommended to tourists visiting Europe at the time when each edition was published. It is a very detailed data source of high value to determine railway track history, in particular from 1978 onwards. The maps published before the 1970s have the inconvenience of being schematic. Third, *'John Bartholomew and Son'* published from its foundation in 1826, numerous different atlases and maps of Europe. Fourth, the *'Historie Chronologique des Chemins de Fer Europeens'* website[1] contains maps of Europe's railways for each year from 1834 through to 1939. This website shows the railway lines for the whole of Europe (with the exception of narrow gauge lines), on a year by year basis, over a period of more than 100 years. However, in some areas, it was necessary to check that all the information provided corresponded to reality. In terms of economic development, we source our data from two databases. For our country level economic development measure GDP per capita, we use the Maddison Project Database (see van Zanden and Bolt, 2013). More precisely, this database provides estimates of GDP per capita in real terms (in 1990 International Geary-Khamis dollars - see Bolt and van Zanden, 2014) for a wide range of countries over a very long period of time. For our purposes we use GDP per capita in real terms for current border countries for every tenth year. Based on the GDP per capita data we calculate the average annual GDP per capita growth rates by using the formula displayed in the appendix.

The second part of the paper is focused on Balkan cities. Population data on urban agglomerations, geographical indicators and railway measures are the key elements. Population data at the municipal level was used to determine the urbanisation process and to calculate urban growth. Research into urbanisation is of analytical interest in itself and is also an accepted indicator of economic development. In this paper we have defined and quantified the part of the population that resides in urban agglomerations. The towns and cities referred to in the current study had populations of 10,000 inhabitants at least in one year (see Stanev, 2011, 2013). In our data the number of population surpasses 10,000 inhabitants in all cities at least in one year. This analysis involves the combined use of census data, municipal border data and data relating to the location of administrative units and any changes to their administrative borders. We then transferred this information to a GIS using georeferenced codes (X/Y coordinates). Having cities territorially located, we calculate some geographical indicators. Distance to coast has been calculated using the straight line distance between each city and the nearest coastline. Elevation has been extracted from the Digital Elevation Model of Europe (GISCO Eurostat[2]). Finally, ruggedness has been calculated in order to get an indicator of topographic heterogeneity on urban surroundings (see Riley, Gloria, and Elliot, 1999). The following Equations 1 and 2 denote the calculation approach for ruggedness:

$$I_R = \overline{I_{R_{(c,d)}}}, \tag{1}$$

where I_R is the average over the values of a certain city region,

$$I_{R_{(c,d)}} = \sqrt{\frac{8 * \sum_{j=d-1}^{d+1} \sum_{i=c-1}^{c+1} (z_{c,d} - z_{i,j})^2}{n}}, \tag{2}$$

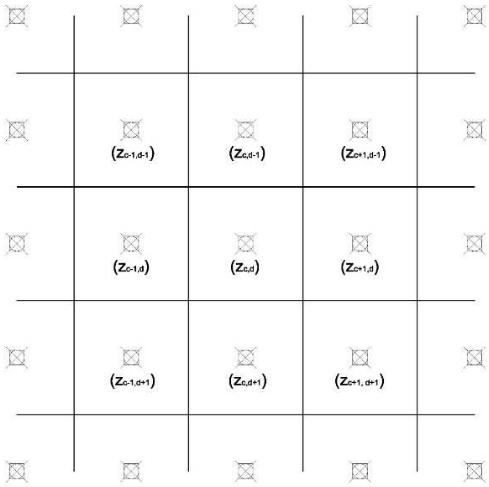
where $I_{R_{(c,d)}}$ is the ruggedness index in a specific cell (c, d), $z_{c,d}$ is the elevation value in the cell (c, d) and $8/n$ is a correction factor that compensates the boundary effect. Figure 4 illustrates the dependency between the different cells. The central point for the calculation is each city, and the adjacent points have been created using a grid of 1,000 meters.

The next step was to assign to each city information related to the nearest railway line. In that sense, we assign two new variables: nationality of railway promoters and hierarchy of the line. Nationality of railway promoters gives us information of the origin of the capital used in the

[1] `http://www.train.eryx.net/html_trains/index_nouveau.htm.`

[2] Digital Elevation Model over Europe from GMES RDA project. It covers 39 member and cooperating countries, with a 3D raster dataset with elevation. The dataset used was made available as tiles (5x5), and georeferenced in ETRS89 coordinates system.

Figure 4: Grid to calculate ruggedness



Source: Own illustration.

moment of railway construction. Hierarchy, furthermore, allows us to understand the importance of the nearest railway in a regional perspective. In that sense, we consider three levels: international railways, representing connection between countries and main ports; primary railways, including main national railways, and other railways (see Stanev, Alvarez, and Marti-Henneberg, 2016).

The last indicator related with railways is the fractality of urban areas. Using the formulation developed by French scholars (see Mandelbrot, 1975; Dupuy, 1991, 2013; Genre-Grandpierre, 1999) adapted to the availability of historical data, we created outer rings around each city at 2,500, 5,000 and 10,000 metres that were intersected with railway lines. With this measure we want to catch the concentration of infrastructure endowment just in those cities that are really becoming regional centres. We use the following formula:

$$l_f = \frac{log(L)}{log(S)}, \tag{3}$$

where I_f is the fractality indicator, L is the railway's length (in km) and S is the area of each outer ring (in km^2). Consequently, the fractality indicator actually captures the railway density around cities.

4 Methodology

Our methodology consists of two different steps. To address our first research question, we employ a panel regression at the country level by using data on European countries from 1830 up to 2010, following the approach of Calderon and Serven (2004). The infrastructure stock is generally regarded as an input for the aggregate production function and therefore for GDP growth. Second, we run a linear multilevel model at the city level by using data on cities of twelve Balkan countries from 1850 up to 2000 to deal with our second research question.

To test for the stationarity of time-series, we apply an augmented-Dickey-Fuller test[3]. The GDP per capita growth rate appears to be stationary, whereas railway density (i.e. railway length in km per 1,000 km^2) and GDP per capita levels highlight non-stationary results. Since the railway construction is zero in some countries at the beginning of the unbalanced panel data, we use an inverse-hyperbolic-sine (ihs) transformation[4], instead of a typical logarithmic transformation. The ihs-transformed railway density displays stationary results, contrary to the ihs-transformed GDP per capita levels which are still non-stationary. By incorporating GDP per capita, our aim is to capture beta convergence, i.e. countries with higher GDP per capita are expected to show a lower GDP per capita growth rate. Alternatively, we generate quartiles of GDP per capita to obtain four different groups. We use these quartiles as additional explanatory variables to compare the more developed countries with the others. With respect to city data, the (ihs-transformed) population level as well as population growth rate appear to be stationary.

Concerning the panel regressions at the country level, data from 1830 up to 2010 in ten-year intervals are available which suggests the use of a panel regression (unbalanced). The Hausman-test recommends the application of fixed effects instead of random effects or pooled OLS estimations. In order to check whether we should incorporate time fixed effects in our panel regressions as well, we compare the AICs[5] and calculate an F-test for the joint-significance of all time dummies. Both approaches suggest the use of time fixed effects in our panel regressions. Given the fact that we use data for such a long time period for current country borders, information on other explanatory variables do not seem to be readily available. The current borders reflect in many cases territorial sub-divisions of historical empires with a certain autochthone set of long-lasting institutions. These borders are useful for reasons of comparability and also represent the structure of the Maddison Project Database providing the historical GDP data. However, we need to expect to suffer from a certain omitted variable bias, although we (partly) control for this by using fixed effects. To diminish the impact of possible simultaneity and to consider a lagged impact as well, we implement the railway measure and the GDP per capita dummies with a one period (i.e. one decade) time lag. Hence, we use the following panel regression baseline model:

$$y_t = \boldsymbol{X_{t-10}}\boldsymbol{\beta} + \boldsymbol{D_t}\boldsymbol{\theta} + \mu_i + \eta_t + \epsilon_t, \tag{4}$$

where y_t is the GDP per capita growth rate (nx1 vector), X_{t-10} is an nxp matrix comprising all time-lagged explanatory variables including the (ihs-transformed) railway density which acts as our main explanatory variable of interest and the quartile of GDP per capita dummies that controls for convergence to a certain extent. D_t reflects an nxh matrix containing institutional control dummies indicating whether a country in the respective decade was a member of the European Union, under Communism, part of Yugoslavia, part of the Habsburg, the Ottoman or the Romanov Empire.[6] Moreover, μ_i and eta_t are the country- and time-fixed effects and ϵ_t is the error term. The panel fixed effects regression applies the ordinary least squares estimation method to produce the estimates.

Apart from the panel regressions at the country level, a linear multilevel regression model at the city level will be employed as well. In general, we observe heterogeneity across cities (within countries) as well as across countries. We therefore use a linear multilevel regression model to take into account the variation at different levels (i.e. cities and countries over a period of time).

3 We basically follow the strategy by Elder and Kennedy (2001) and apply different numbers of lags, a trend (for railway density) and demeaning. In addition, we employ a Phillips-Perron test which represents a Dickey-Fuller statistics that is robust to serial correlation by using Newey-West standard errors.

4 $ihs(y) = ln(y + \sqrt{y^2 + 1})$, see for example Burbidge, Magee, and Robb (1988).

5 Akaike information criterion (AIC): model with minimum AIC is preferred.

6 Note: $p + h = r$, where r is the total number of our explanatory variables.

More specifically, a multilevel regression enables us to consider the data structure (e.g. cities are clustered in countries) and to incorporate micro and macro variables in one regression model (see De Leeuw, Meijer, and Goldstein, 2008). In case of a two level model, the estimation procedure is similar to a two stage model, where micro level regressions with micro level indicators are applied, followed by macro level regressions using the estimated effects from first stage. However, in a multilevel regression model both stages are fitted simultaneously (see Gelman and Hill, 2006). In general, we use the following three level model which is stated in a clustered-data representation by taking into account that we have data on 588 cities (unbalanced panel data) clustered in 12 countries, between the years 1850 and 2000 (see Stata, 2013):

$$y_{jk} = \boldsymbol{X_{jk}\beta} + \delta t + u_k + u_{jk} + \epsilon_{jk}, \tag{5}$$

$$u_k \sim N(0, \sigma_3^2) \qquad u_{jk} \sim N(0, \sigma_2^2) \qquad \varepsilon_{jk} \sim N(0, \sigma_\varepsilon^2)$$

where u_k as well as u_{jk} represent the random effects corresponding to the intercepts of countries and cities (see Gelman and Hill, 2006). All three error components are independent. At the lowest level we have $i = 1, \ldots, n_{jk}$ observations (i.e. observations for each city over the respective years), since these observations are clustered within $j = 1, \ldots, M_k$ cities (second-level) and these are nested among $k = 1, \ldots, M$ countries (highest-level). Hence, each jk city provides n_{jk} observations. X represents an $n_{jk}xl$ matrix, that includes explanatory variables at the city as well as the country level, whereas the dependent variable y_{jk} ($n_{jk}x1$ vector) records the city's population growth. δ captures the trend in our data. In our analysis we use the time-lagged (ihs-transformed) population level, the time-lagged railway fractality (our railway accessibility measure), nearest railway's hierarchy level (international/national/secondary), origin of the capital used to build the nearest railway tracks for a city, the distance to the capital city and geographical measures (elevation, distance to coast and ruggedness) as available explanatory variables at the micro (city) level. By contrast, our explanatory variables at the macro (country) level are a number of conflict and crisis dummies, the (ihs-transformed) railway density as well as the GDP per capita growth rate.[7]

Since we use city level data, it is likely that there exist interdependencies between different locations, i.e. the population growth rate of one city depends additionally on characteristics of other cities.[8] To integrate spatial dependency in our multilevel model (see Corrado and Fingleton, 2012), we consider that cities are influenced by other geographically connected cities. [9] As proposed by the spatial econometric literature (see for example Dall'Erba and Gallo, 2008), we generate a spatial weight matrix W (NxN) based on the distances between cities ($d_{jk,s}$ refers to the distance between city jk and s). N represents the total number of cities across countries. The distance-based weight matrix W is defined as:

$$w_{jk,s} = \begin{cases} 0 & \textit{if } jk = s \; \forall \; jk,s \\ \frac{1}{d_{jk,s}} & \textit{if } jk \neq s \; \forall \; jk,s \end{cases}$$

[7] A detailed description of the respective explanatory variables can be found in the appendix.

[8] In order to test whether spatial dependency does exist, we have calculated Moran's I statistic. The statistic indicates that there persists spatial dependency between cities.

[9] In the basic linear multilevel model we actually already consider correlation between cities in the error term, however this only concerns cities in the same country.

We enlarge our linear multilevel model by using the row-standardized W matrix[10] and introducing the spatial lag $W_{jk}B$:

$$y_{jk} = \boldsymbol{X_{jk}\beta} + \boldsymbol{W_{jk}B\theta} + \delta t + u_k + u_{jk} + \epsilon_{jk}, \tag{6}$$

where W_{jk} refers to the jk^{th} row of our W matrix ($W_{jk} = I_{n_{jk}} \otimes w_{jk}$) and B concerns the explanatory variables for the spatial lag and contains information about all cities (within and across countries) over the years (i.e. data on all cities stacked by years). In this model we are primarily focused on local spatial externalities, which occur at directly connected other locations, i.e. exogenous interaction effects (see Elhorst and Vega, 2013). Since we are mainly interested in the fractality indicator (i.e. our railway accessibility measure at the city level), we just use this variable for our spatial lag (i.e. $B \subseteq X$). Thus, we consider the impact of railway accessibility of neighbouring cities as indirect (spillover) effects. The estimates of the linear (spatially augmented) multilevel model are produced by running a maximum likelihood estimation.

5 Results

The first results of our panel fixed effects regression model at the country level presented in equation 4 are summarized in Table 1. Specification *(1)* represents our baseline model where we analyse the simple impact of railway density on the GDP growth rate of European countries after controlling for a number of variables which we have discussed above. This model is extended and nested in the other three specifications. In specification *(2)* we introduce a quadratic term of the railway density measure in order to look at increasing or decreasing scale effects emanating from a higher railway mileage. In *(3)* we implement an interaction term with a dummy variable that indicates the Balkan countries in the sample in order to capture differences in the effect of railway density compared to the rest of the (more developed) European countries in our sample. Since we apply fixed effects models, the separate Balkan dummy is dropped from the analysis. Moreover, we generate an interaction term between the railway length measure and the quartiles of GDP per capita to examine whether the effect of railway length is linked to the different levels of economic development of countries.

The results reveal a robust positive impact of the (ihs-transformed) railway density on GDP per capita growth. The estimated coefficient of our railway measure is statistically significant in all four specifications. Furthermore, we do not find significant results for the quartile of GDP per capita dummies. The 'member'-dummies point to a significant positive growth effect for European Union countries and a significant negative growth for communist countries as well as countries within Yugoslavia. Moreover, the Empire dummies indicate a negative growth impact, whereby the Romanov Empire reveals insignificant results. Concerning the impact of the railway density, the results highlight some interesting further features. The squared (ihs-transformed) railway density shows a significant negative effect implying a positive, however, declining total impact of the (ihs-transformed) railway density. Moreover, we observe a significant higher impact for Balkan countries and likewise for less developed countries. Thus, the impact of railways might depend on the level of development of countries. Less developed countries with a lower railway stock seem to be able to push economic growth through railway investments, which might indicate a potential for infrastructure investment generated catching-up effects.

[10] Row-standardized means that all rows of the W matrix sum up to one, i.e. $\sum_{s=1}^{N} w_{jk,s} = 1$.

Table 1: Panel fixed effects regression model (1830-2010)

Dependent variable:	GDP per capita growth rate $_t$ 1830-2010			
	(1)	(2)	(3)	(4)
Railway density $_{t-10}$	0.360**	0.704***	0.245*	0.648***
	(0.157)	(0.152)	(0.133)	(0.195)
4^{th} quartile of GDP per capita $_{t-10}$	-0.495	-0.582	-0.307	-0.825
	(0.550)	(0.470)	(0.514)	(0.534)
3^{th} quartile of GDP per capita $_{t-10}$	0.202	0.0972	0.325	-0.284
	(0.370)	(0.338)	(0.339)	(0.410)
2^{th} quartile of GDP per capita $_{t-10}$	0.136	0.0417	0.171	-0.208
	(0.302)	(0.307)	(0.296)	(0.392)
Railway density $_{t-10}$ * railway density $_{t-10}$		-0.0858**		
		(0.0315)		
Railway density $_{t-10}$ * Balkan			0.540***	
			(0.135)	
Railway density $_{t-10}$* 4^{th} quartile of GDP per capita $_{t-10}$				-0.508***
				(0.164)
Railway density $_{t-10}$* 3^{th} quartile of GDP per capita $_{t-10}$				-0.226
				(0.150)
Railway density $_{t-10}$* 2^{th} quartile of GDP per capita $_{t-10}$				-0.231
				(0.166)
EU $_t$	1.244***	1.232***	1.271***	1.343***
	(0.379)	(0.367)	(0.375)	(0.371)
Communist $_t$	-1.936***	-1.933***	-1.988***	-1.787***
	(0.621)	(0.618)	(0.617)	(0.622)
Yugoslavia $_t$	-3.537***	-3.537***	-3.624***	-3.540***
	(1.260)	(1.263)	(1.262)	(1.276)
Habsburg Empire $_t$	-1.010***	-1.142***	-1.129***	-0.914**
	(0.307)	(0.286)	(0.263)	(0.352)
Ottoman Empire $_t$	-1.583**	-1.211**	-0.583	-0.721
	(0.616)	(0.553)	(0.492)	(0.628)
Romanov Empire $_t$	-0.365	-0.306	-0.490*	-0.306
	(0.226)	(0.216)	(0.243)	(0.224)
R^2	0.560	0.564	0.566	0.569
Adjusted R^2	0.523	0.526	0.528	0.528
R^2 between	0.344	0.308	0.314	0.312
R^2 within	0.266	0.314	0.26	0.298
Number of countries	33	33	33	33
N	351	351	351	351

Note: In the panel fixed-effects model we use time as well as country fixed effects. Robust standard errors in parentheses. Railway density $_{t-10}$ is ihs-transformed. EU $_t$, Communist $_t$, Yugoslavia $_t$, Habsburg Empire $_t$, Ottoman Empire $_t$ and Romanov Empire $_t$ are time-variant dummy variables. Balkan indicates a dummy for the Balkan countries (time-invariant). This dummy is dropped from the regression due to the application of the fixed effects estimation. Turkey is excluded, since data only captures the European area of Turkey; * p<0.1, ** p<0.05, *** p<0.01.

Since we use a long time horizon (1830-2010), we need to check whether there are structural breaks in our estimates. In order to do this, we employ a Chow-test with a suspected structural break in 1950 (in fact the decade from 1940-1950 including World War II). In general, the Second World War was characterised by new technological innovations which have resulted in the mass production of cars and airplanes in the aftermath. Accordingly, we create a time-dummy for before 1950_t capturing the time before the respective threshold. To check for a structural break in our railway estimates, we create an interaction term between before 1950_t and our railway measure. We run the regression by only considering a specific number of countries (Austria, Belgium, Switzerland, Denmark, Spain, France, Greece, Italy, Sweden, United Kingdom) to minimize the impact of varying countries (unbalanced panel). Then we apply an F-test to test for the joint significance between before 1950_t and its interaction term with the railway density. The F-test highlights a significant structural break. Due to this result, we estimate our models from Table 1 for the period 1830 to 1950 and 1960 to 2010 separately by considering all available countries.

Table 2 shows the results of our regressions for the pre-World War II (WWII) era. In general, the results are similar to the results of our regressions with the full sample from Table 1. The (ihs-transformed) railway density depicts a robust significantly positive impact on GDP per capita growth. However, as indicated by *(2)* we do not find evidence for a positive declining railway impact. Moreover, we find a higher positive effect for Balkan countries compared to other European countries, whereby this result is only weakly significant. Likewise, the impact of the railway system appears to be higher for less developed European countries compared to the most developed European countries.

In addition to the pre-WWII era we also apply the regressions for the post-WW II era. Table 3 presents the results using the sample from 1960 to 2010. In the baseline model *(1)* there is no significant impact of the (ihs-transformed) railway density. By contrast, we find a strongly significant non-linear effect implying a highly positive impact of the railway infrastructure at the beginning, but declining with an increasing stock of railway infrastructure. Compared to Table 1 and Table 2, we find a different result in specification *(3)*. Although we find a highly significantly positive impact for Balkan countries, the impact for other European countries is highly negative. Railway infrastructure reached its peak in the 1960s in most European countries. Compared to Balkan countries, most European countries have been characterised by a higher railway density. Consequently, further network expansion seems to be counterproductive in the more developed European countries. In fact many Western European countries reduced their network but upgraded the quality of the remaining network, which however is impossible for us to capture. Notwithstanding, Balkan countries are still characterised by an infrastructural backwardness and further investments in the railway infrastructure appear to have positive effects.

Summing up, Table 2 and Table 3 show that the impact of railway infrastructure might be different over time. Railway stocks might have had a crucial economic impact during the 19^{th} century and the first half of the 20^{th} century, particularly in the light of the industrial revolution. This impact seems to have lost importance in the second half of the 20^{th} century and the early 21^{st} century for most European countries, which might be connected to the already existing railway stocks in the more developed European countries and additionally to new technological innovations (e.g. mass production of cars and airplanes) which have acted as substitutes to the railway transport.

As already discussed, the regressions are expected to suffer from an omitted variable bias and additionally from simultaneity. Therefore, we conduct a test for endogeneity on the suspected endogenous explanatory variable[11]. We obtain a highly insignificant result, which implies that

[11] We also apply an instrumental variable estimation by using (ihs-transformed) railway density$_{t-20}$ as well as railway density growth rate$_{t-10}$ as instruments (relevant, valid, not weak). The results highlight a significantly positive impact of railway infrastructure as well.

Table 2: Panel fixed effects regression model (1830-1950)

Dependent variable:	GDP per capita growth rate $_t$ 1830-1950			
	(1)	(2)	(3)	(4)
Railway density $_{t-10}$	0.303*	0.437***	0.290*	0.454**
	(0.146)	(0.148)	(0.145)	(0.181)
4th quartile of GDP per capita t-10	-0.712	-0.791	-0.603	-0.758
	(0.908)	(0.869)	(0.903)	(0.819)
3^{th} quartile of GDP per capita $_{t-10}$	0.186	0.0985	0.281	-0.156
	(0.541)	(0.512)	(0.530)	(0.469)
2^{th} quartile of GDP per capita $_{t-10}$	0.134	0.0607	0.211	-0.117
	(0.385)	(0.364)	(0.366)	(0.255)
Railway density $_{t-10}$ * railway density $_{t-10}$		-0.0371		
		(0.0223)		
Railway density $_{t-10}$* Balkan			0.206*	
			(0.106)	
Railway density $_{t-10}$* 4^{th} quartile of GDP per capita $_{t-10}$				-0.318**
				(0.114)
Railway density $_{t-10}$* 3^{th} quartile of GDP per capita $_{t-10}$				-0.0701
				(0.0963)
Railway density $_{t-10}$* 2^{th} quartile of GDP per capita $_{t-10}$				-0.123
				(0.122)
Communist $_t$	-2.792***	-2.757***	-2.839***	-2.649***
	(0.858)	(0.858)	(0.862)	(0.905)
Habsburg Empire $_t$	-0.627*	-0.644*	-0.690*	-0.423
	(0.345)	(0.333)	(0.350)	(0.376)
Romanov Empire $_t$	-1.152***	-1.073***	-1.178***	-1.028***
	(0.244)	(0.252)	(0.258)	(0.255)
R^2	0.420	0.423	0.422	0.432
Adjusted R^2	0.355	0.354	0.354	0.356
R^2 between	0.114	0.105	0.0705	0.135
R^2 within	0.268	0.294	0.268	0.274
Number of countries	21	21	21	21
N	180	180	180	180

Note: In the panel fixed effects model we use time as well as country fixed effects. Robust standard errors in parentheses. Railway density $_{t-10}$ is ihs-transformed. Communist $_t$, Habsburg Empire $_t$ and Romanov $_t$, are time-variant dummy variables. Ottoman Empire $_t$ cannot be considered due to limited data availability. Turkey is excluded, since data only captures the European area of Turkey; * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Table 3: Panel fixed effects regression model (1960-2010)

Dependent variable:	GDP per capita growth rate $_t$ 1960-2010			
	(1)	(2)	(3)	(4)
Railway density $_{t-10}$	-0.327	9.050***	-4.508***	0.880
	(1.604)	(2.481)	(1.334)	(1.457)
4^{th} quartile of GDP per capita $_{t-10}$	-1.979**	-1.409**	-1.677**	-1.709**
	(0.816)	(0.680)	(0.642)	(0.693)
3^{th} quartile of GDP per capita $_{t-10}$	-1.576**	-1.227*	-1.427**	-1.792**
	(0.731)	(0.663)	(0.660)	(0.680)
2^{th} quartile of GDP per capita $_{t-10}$	-0.941	-0.894	-0.893*	-1.062
	(0.577)	(0.542)	(0.520)	(0.633)
Railway density $_{t-10}$ * railway density $_{t-10}$		-1.334***		
		(0.351)		
Railway density $_{t-10}$* Balkan			6.640***	
			(1.640)	
Railway density $_{t-10}$* 4^{th} quartile of GDP per capita $_{t-10}$				-4.294***
				(1.339)
Railway density $_{t-10}$* 3^{th} quartile of GDP per capita $_{t-10}$				-3.164*
				(1.630)
Railway density $_{t-10}$* 2^{th} quartile of GDP per capita $_{t-10}$				-1.606
				(1.045)
EU $_t$	1.661***	1.575***	1.355**	1.562***
	(0.503)	(0.492)	(0.500)	(0.520)
Communist $_t$	-1.699**	-1.942**	-1.974**	-1.993**
	(0.819)	(0.784)	(0.806)	(0.832)
Yugoslavia $_t$	-3.492**	-3.765***	-4.136***	-3.924***
	(1.307)	(1.299)	(1.299)	(1.314)
R^2	0.551	0.577	0.587	0.576
Adjusted R^2	0.517	0.542	0.553	0.535
R^2 between	0.059	0.129	0.0374	0.0782
R^2 within	0.373	0.332	0.202	0.304
Number of countries	33	33	33	33
N	171	171	171	171

Note: In the panel fixed effects model we use time as well as country fixed effects. Robust standard errors in parentheses. Railway density $_{t-10}$ is ihs-transformed. Turkey is excluded, since data only captures the European area of Turkey; * p<0.1, ** p<0.05, *** p<0.01.

the already obtained estimate is consistent as well. Thus, our estimator for the railway density can be interpreted in a statistically causal way. This might be linked as well to the properties of our dependent and explanatory variable. By following the guidelines of Bellemare, Masaki, and Pepinsky (2015), we find a confirmation for a valid justification to use time-lagged explanatory variables to identify a statistically causal relationship. There is a (contemporaneous) reverse-causality from Y on X and the statistically causal effect of X on Y operates with a one period lag[12].
Given our results, we can give a statistically causal interpretation of the positive impact of the time-lagged (ihs-transformed) railway density on the GDP growth rate. According to Woolley (2011), results by using ihs-transformed variables can be interpreted in the same way as in case of a traditional logarithmic transformation, with the exception of small values of the original variable[13]. Therefore, we can state that a 10% increase in the railway density increases GDP growth by 0.03 percentage points (Table 1 specification *(1))*.

In general, our results seem to be in line with the findings of Canning and Pedroni (2008) as well as Calderon and Serven (2004). But, since the impact of infrastructure suggests to be related to the overall development of countries and in addition diminishes in case of higher infrastructure stocks, our results correspond as well to the findings of Canning and Bennathan (2000).

In addition to fixed-effects estimations at the country level, we also employ a linear multilevel model for city development in the Balkans. Since economic development is also related to population growth (and we do not have information on GDP per capita growth of cities), it is appropriate to analyse its determinants. Thereby, we basically follow the econometric approach applied by Jiang, Deng, and Seto (2012) and use explanatory variables at the city and at the country level. In this regard, our main variables of interest are the time-lagged fractality information at the city level and the time-lagged (ihs-transformed) railway density at the country level. More precisely, fractality is a measure to capture the railway density within a defined area around the city. Therefore, we compute this measure for different outer rings where *(A)* refers to a ring around each city at 2.5 km, *(B)* at 5 km and *(C)* at 10 km. This enables us to provide a robustness check. Contrary to the fixed-effects estimations, the sample of the multilevel model comprises only 12 countries including Albania, Bosnia, Bulgaria, Greece, Croatia, Montenegro, Macedonia, Romania, Serbia, Slovenia, Turkey and Kosovo. Table 1 summarizes the first results of the linear multilevel model by considering the three different outer rings for factuality *(A)*, *(B)* and *(C)*. With respect to the macro (country) level, we just include conflict and crisis dummies as a first approach.

Table 4 is structured according to fixed and random effects. Since a linear multilevel model with a random intercept is used, we observe three different random effects, one for each level in the hierarchy. All three random effects show significant result implying that our defined hierarchy seems to be appropriate. Our implemented explanatory variables reveal varying, but robust results. The time-lagged (ihs-transformed) population level shows a robust significantly negative impact on population growth, which means that the higher the population stock the lower the population growth (to a certain extent a sign of convergence). Smaller cities are likely to grow faster, probably due to greater land availability (lower land prices) and thus more options for firms to locate and expand (see Giuliano, Redfearn, Agarwal, and He, 2012). By contrast, our time-lagged railway accessibility measure (i.e. fractality) displays a robust significantly positive impact on population growth, which probably reflects an agglomeration effect to some extent. The improved economic opportunities attract new firms to establish subsidiaries as well as present firms to expand their businesses. Moreover, this effect might also capture network effects due to the access to the railway

[12] By incorporating railway density$_t$ in our baseline regression model as an additional explanatory variable, we obtain an insignificant result.

[13] $|y_t| < 2$ represents small values. Concerning railway density we identify 15 observations with small values. However, our estimation results are robust. Estimations without the 15 observations display similar results.

network including an easier access to new markets. However, the impact diminishes from *(A)* to *(C)*, which might indicate the crucial role of railway accessibility especially in the inner centre of a city. Concerning our geographical measures, the distance to the coast and slightly ruggedness of the area appear to affect city's population growth. By considering the distance to coast, we additionally capture a possibly easier accessibility to harbours for cities that are close to the coast. The elevation of a city seems to be irrelevant for city's population growth. Similarly, the function of the railway (national or international railway) does not seem to have an impact, whereas the origin of capital to build railways from Austro-Hungary and France depicts significantly negative results. This might be correlated with the special interests (i.e. war, connection to eastern countries) in connection with the construction of railways in the Balkans (see Dzhaleva-Chonkova, 2007). Furthermore, the significant result of the distance to the capital city emphasizes the important role of the country's capital for economic development and population growth. The proximity to the capital might be associated with a well-developed general infrastructure, a better market access and better labour market conditions. Besides, the conflict and crisis dummies point to a significant impact of the 1^{st} World War (WWI) and the struggles in relation to the fall of the Communism. Surprisingly, the 2^{nd} World War (WWII) seems to have had a much lower impact, based on its weakly significant results.

In Table 5 we expand the previous linear multilevel model and consider the time-lagged (ihs-transformed) railway density and the time-lagged GDP per capita growth rate as additional explanatory variables at the country level. Through the incorporation of the overall railway measure, we shall control for location-specific and network effects as well as other spillover effects which occur due to railway accessibility in other cities, separately. Although we observe certain changes in the estimated coefficients at the city level, particularly for the time-lagged (ihs-transformed) population level and the time-lagged fractality, all coefficients at the city level show quite robust results. At the country level we discover a change for the WWII and the Great Depression dummy, where the latter refers to the period from 1920 up to 1940[14]. The two newly introduced explanatory variables display highly significantly positive impacts on city's population growth. The time-lagged GDP per capita growth rate controls for the overall economic development of a respective country. The positive impact of the time-lagged (ihs-transformed) railway density[15] might indicate potential externalities which operate within countries emanating from a well-developed railway system, given that we already control for the individual city's railway accessibility, city's size, city's proximity to harbours and capital city as well as geographical conditions. These externalities might comprise network effects, which refer to cities with a connection to the railway system, as well as other spillover effects occurring *inter alia* due to higher demand from neighbouring cities. Cities which are located closer to centres may enjoy greater urbanisation economies and overall access to labour force (see Giuliano, Redfearn, Agarwal, and He, 2012). However, according to Bryan and Jenkins (2015) as well as Stegmueller (2013) we need to be cautious about claiming relationships for country variables, especially for the latter implemented explanatory variables, because we use a small number of countries in our multilevel model. In this regard, Stegmueller (2013) points out that in case of a random intercept model the estimates and the confidence interval coverage of the estimated macro effects are only biased to a limited extent, as long as more than 15 countries are available. The only estimates that remain unaffected by a small number of countries are the fixed parameters at the micro level, given that there is not a random component attached to a slope as well (see Bryan and Jenkins, 2015). Thus, although we find highly significant results, we need to be cautious in interpreting country effects.

[14] Without the time-lagged GDP per capita growth rate WWII shows an insignificant result, whereas Great Depression reveals a significantly negative impact (quite similar to results of Table 4). Thus, as expected the time-lagged GDP per capita growth rate captures the impact of the overall economic development of a country on the population growth of cities in this country. By including this variable in our regression, the impact of the Great Depression loses its significance. In addition, this implies that given the control for the overall economic development, WWII displays a significant positive effect. This might mainly reflect the time of the post-WWII era (after 1944/45), where it is likely that population growth increased again.

[15] Only 44 out of 2,347 observations have small values concerning the ihs-transformation.

Since we want to incorporate additionally the impact of the neighbouring cities' accessibility to railway tracks in our model, we apply the linear multilevel model augmented by a spatial lag in the explanatory variable. This enables us to distinguish between direct and indirect effects resulting from railway infrastructure stocks in the respective cities, which allow us again to differentiate between location-specific and spillover effects, however in a more sophisticated way (i.e. distance based). Table 6 depicts the results of the regressions without the time-lagged (ihs-transformed) railway density and the time-lagged GDP per capita growth rate, however with the additional explanatory variable at the city level capturing railway accessibility of city's neighbours, i.e. the time-lagged neighbours' fractality. We notice quite similar results compared to Table 4. Though the coefficients change a bit, the signs and significances of the variables remain the same, highlighting again robust results. On the one hand we find a significantly smaller positive direct effect as before, but, on the other hand we additionally provide an even stronger significantly positive indirect effect of the time-lagged railway accessibility measure on city's population growth. The strong significantly positive impact of the time-lagged neighbours' fractality, in particular in relation to the inner centre of the cities nearby, implies a strong further evidence for spillover effects, caused by interdependencies with cities of the same and of other countries (i.e. cross-border). As already outlined, the effect of the railway accessibility in the own city declines by considering broader areas around the city. Likewise, the indirect impact through the railway accessibility in the cities nearby decreases too, but to a higher extent. Although we observe a significantly negative impact of WWII in this model specification, the impact remains small compared to the other country dummies.

In a further step we incorporate additionally the time-lagged (ihs-transformed) railway density and the time-lagged GDP per capita growth rate as additional explanatory variables at the country level in our spatially augmented linear multilevel model. The results in Table 7 underline our robust results once again. The impact of the time-lagged fractality and the (ihs-transformed) railway density reveal significantly positive results, quite similar to those of Table 5. Similarly, the impact of the time-lagged neighbours' fractality remains significant in this specification. As we have already argued, the time-lagged (ihs-transformed) railway density might possibly be associated with spillover effects operating within countries. Since neighbours' fractality also accounts for cross-border interdependencies, we might conclude that there are spillovers reasoned by the accessibility to railways occurring within and across countries. By considering the overall time-lagged (ihs-transformed) railway length of a country, the strong effect of the time-lagged neighbours' fractality does not vanish, although its magnitude and significance diminish. We also run the models based on a distance-based W matrix, where we only consider the neighbours only within a country (see Table 17 and Table 18 in the appendix). The results reveal highly significant, positive impacts. However, the indirect effect becomes insignificant after incorporating the time-lagged (ihs-transformed) railway density as well. This can be regarded as a further evidence that indirect effects which occur within countries are mainly captured by the overall railway density, whereas cross-border indirect effects are controlled by the neighbours' fractality, given that both variables are included.

Our results support the essential role of railway accessibility on population growth, outlined by Kotavaara, Pukkinen, Antikainen, and Rusanen (2014), da Silveira, Alves, Lima, Alcantara, and Puig (2011) and Koopmans, Rietveld, and Huijg (2012). In addition, we give an intuition of the separated location-specific as well as spillover effects. Contrary to Caruana-Galizia and Martí-Henneberg (2013), we find positive economic effects arising from the railway infrastructure of neighbours for Balkan cities[16].

[16] Caruana-Galizia and Martí-Henneberg (2013) apply regional real income data as the dependent variable. The data comprise regions of Spain, Britain, Italy, Austria-Hungary, Sweden, France and Germany.

6 Conclusion

In this paper we examine the role of railway infrastructure for European and particularly for Southeast European countries by addressing two different research questions. The first question concerns the impact of railway systems at the national level and is defined as follows, *'What is the impact of a higher railway mileage on economic growth, in particular for less developed (i.e. Southeast European) countries?'* Furthermore, we define a further research question for the city level, *'What are the direct and indirect effects of railway accessibility on population growth of Balkan cities?'* In order to analyse these two research questions, we source data per decade from the Maddison Database and from the Historical Geographical Information System for Europe (HGISE) based on current country borders.

In a first step we apply a panel fixed effects regression model at the country level using data from 1830 to 2010. Thereby, we show a positive impact of railway infrastructure on GDP per capita growth and provide evidence of a significantly higher impact for less developed European countries, especially Southeast European countries. Although there appears to be an overall positive effect emanating from a pronounced infrastructure railway system, its role seems to have changed during the centuries. While railway played an essential role during the Second Industrial Revolution in the late 19^{th} century, it has lost of its power from the mid of the 20^{th} up to the early 21^{th} century for most European countries. This might be linked to further technological innovations which have functioned as substitutes for railway transport. Moreover, more developed European countries seem to already have a sufficiently pronounced railway system. Overall, our findings correspond to the economic literature, since the impact of railway infrastructure seems to depend on the stage of development of a country and the time period for which the impact is assessed. Nevertheless, for Balkan countries an extension of the railway network proved to be beneficial also in the post-WW II period.

In a second step we apply a linear spatially augmented multilevel regression model, where we analyse the impact of railway accessibility at national as well as regional level on population growth of Balkan cities. For this regional analysis we use data for Balkan cities from 1850 to 2000. Here, population growth acts as a proxy for economic development. Higher population growth is likely to be correlated with stronger economic development. We find a positive effect of railway accessibility on cities' population growth and even a higher positive (indirect) spillover effect, where the latter is detected within as well as across country borders. The direct effect indicates a straight growth impact if the city has access to a railway transport system after controlling for specific city characteristics (e.g. population size, distance to capital city and to coast, geographical measures). This might indicate an agglomeration effect resulting from the access to a railway transport system. Moreover, the positive spillover effects emphasise the benefits of a city when the neighbouring cities have a connection to the railway system. Therefore, it seems to be crucial to be located next to a city that has a railway connection. These externalities might concern network effects as well as other spillover effects, where the latter might arise from a higher demand from neighbouring cities. Positive network effects imply an additional positive effect for cities with railway access because the railway system is generally used by more cities (i.e. easier market access).

The results of our regressions point to a crucial role of (railway) transport infrastructure for economic development at the country as well as the local level especially for Southeast European economies. Since Balkan countries are still characterised by infrastructure bottlenecks, our analysis promotes the discussion on investments in infrastructure to foster economic development in Southeast Europe.

Table 4: Linear mixed model - city

Dependent variable:		Population growth rate $_t$ 1850-2000 (A)	(B)	(C)
Fixed effects:				
Micro:	Fractality $_{t-10}$	0.852***	0.582***	0.447***
		(0.150)	(0.0901)	(0.0651)
	Population level $_{t-10}$	-0.627***	-0.643***	-0.646***
		(0.0496)	(0.0498)	(0.0497)
	Distance to coast	-0.207***	-0.215***	-0.225***
		(0.0561)	(0.0561)	(0.0561)
	Elevation	0.0730	0.0778	0.0836
		(0.0554)	(0.0553)	(0.0552)
	Ruggedness	-0.0707**	-0.0667*	-0.0685*
		(0.0358)	(0.0358)	(0.0356)
	International railway $_{t-10}$	-0.107	-0.109	-0.0996
		(0.114)	(0.114)	(0.114)
	National railway $_{t-10}$	0.0321	0.0262	0.0271
		(0.119)	(0.118)	(0.118)
	Capital from Austro-Hungary $_t$	-0.284**	-0.304***	-0.319***
		(0.117)	(0.117)	(0.117)
	Capital from France $_t$	-0.795**	-0.824***	-0.826***
		(0.309)	(0.309)	(0.308)
	Capital from Germany $_t$	0.0162	0.00813	-0.00356
		(0.130)	(0.130)	(0.130)
	Capital from United Kingdom $_t$	0.355	0.364	0.358
		(0.225)	(0.225)	(0.225)
	Capital from Germany/France $_t$	0.142	0.115	0.0887
		(0.272)	(0.271)	(0.271)
	Distance to capital city	-0.363***	-0.355***	-0.349***
		(0.0433)	(0.0432)	(0.0431)
Macro:	WWI $_t$	-1.451***	-1.470***	-1.484***
		(0.147)	(0.147)	(0.147)
	WWII $_t$	-0.176*	-0.194*	-0.201**
		(0.101)	(0.101)	(0.101)
	Great Depression $_t$	-0.616***	-0.635***	-0.646***
		(0.0941)	(0.0941)	(0.0942)
	Fall of Communism $_t$	-1.845***	-1.826***	-1.816***
		(0.0890)	(0.0892)	(0.0892)
	Ottoman decline $_t$	-0.788***	-0.786***	-0.789***
		(0.176)	(0.175)	(0.175)
	Trend	0.00886***	0.00829***	0.00787***
		(0.00143)	(0.00144)	(0.00145)
	Constant	-5.694**	-4.537*	-3.739
		(2.684)	(2.707)	(2.725)
Random effects:				
	Country level	-0.765***	-0.751***	-0.749***
		(0.270)	(0.270)	(0.269)
	Between cities	-0.268***	-0.271***	-0.276***
		(0.0689)	(0.0688)	(0.0690)
	Within cites	0.545***	0.544***	0.543***
		(0.0125)	(0.0125)	(0.0125)
Countries		12	12	12
N		3,935	3,935	3,935

Note: Standard errors in parentheses. Population level$_{t-10}$, distance to coast, elevation and ruggedness are ihs-transformed. International railway$_t$, and national railway$_t$ (both with basegroup other railways) as well as capital from Austro-Hungary$_t$, capital from France$_t$, capital from Germany$_t$, capital from UK$_t$ and capital from Germany/France$_t$ (with basegroup domestic sources) are dummy variables. The model represents a random-intercept three-level-model. The three different regressions refer to different basis concerning the calculation of fractality $_{t-10}$ ((A) 2,500 m, (B) 5,000 m and (C) 10,000 m). Distance to coast, elevation, ruggedness and distance to capital city are constant over time. Random effects parameters are displayed in log of standard deviations; * p<0.1; ** p<0.05; *** p<0.01.

Table 5: Linear mixed model - extended

Dependent variable:		Population growth rate $_t$ 1850-2000		
		(A)	(B)	(C)
Fixed effects:				
Micro:	Fractality $_{t-10}$	0.348**	0.264***	0.223***
		(0.155)	(0.0962)	(0.0708)
	Population level $_{t-10}$	-0.236***	-0.248***	-0.254***
		(0.0478)	(0.0483)	(0.0484)
	Distance to coast	-0.198***	-0.203***	-0.209***
		(0.0501)	(0.0502)	(0.0503)
	Elevation	0.0830*	0.0860*	0.0893*
		(0.0480)	(0.0481)	(0.0481)
	Ruggedness	-0.0706**	-0.0689**	-0.0695**
		(0.0306)	(0.0306)	(0.0305)
	International railway $_t$	-0.0779	-0.0773	-0.0699
		(0.113)	(0.113)	(0.113)
	National railway $_t$	0.142	0.141	0.142
		(0.119)	(0.119)	(0.119)
	Capital from Austro-Hungary $_t$	-0.410***	-0.423***	-0.433***
		(0.118)	(0.118)	(0.118)
	Capital from France $_t$	-0.867***	-0.890***	-0.899***
		(0.315)	(0.316)	(0.316)
	Capital from Germany $_t$	0.252**	0.239*	0.226*
		(0.125)	(0.125)	(0.125)
	Capital from United Kingdom $_t$	-0.0581	-0.0544	-0.0625
		(0.288)	(0.288)	(0.288)
	Capital from Germany/France $_t$	0.0270	0.0128	-0.00111
		(0.265)	(0.265)	(0.265)
	Distance to capital city	-0.199***	-0.195***	-0.192***
		(0.0418)	(0.0418)	(0.0418)
Macro:	Railway density $_{t-10}$	0.581***	0.570***	0.559***
		(0.120)	(0.121)	(0.121)
	GDP per capita growth rate $_{t-10}$	0.0937***	0.0937***	0.0938***
		(0.0149)	(0.0149)	(0.0149)
	WWI $_t$	-1.793***	-1.790***	-1.786***
		(0.220)	(0.220)	(0.220)
	WWII $_t$	0.802***	0.800***	0.801***
		(0.164)	(0.164)	(0.164)
	Great Depression $_t$	-0.282	-0.279	-0.275
		(0.233)	(0.232)	(0.232)
	Fall of Communism $_t$	-1.138***	-1.138***	-1.138***
		(0.114)	(0.114)	(0.114)
	Ottoman decline $_t$	-0.670**	-0.664**	-0.659**
		(0.274)	(0.274)	(0.274)
	Trend	-0.0173***	-0.0172***	-0.0171***
		(0.00289)	(0.00289)	(0.00289)
	Constant	38.47***	38.32***	38.18***
		(5.405)	(5.403)	(5.401)
Random effects:				
	Country level	-0.115	-0.109	-0.108
		(0.237)	(0.237)	(0.237)
	Between cities	-0.855***	-0.852***	-0.854***
		(0.151)	(0.151)	(0.151)
	Within cites	0.475***	0.475***	0.474***
		(0.0167)	(0.0167)	(0.0167)
Countries		11	11	11
N		2347	2347	2347

Note: Standard errors in parentheses. Population level$_{t-10}$, distance to coast, elevation and ruggedness are ihs-transformed. International railway $_t$, and national railway$_t$ (both with basegroup other railways) as well as capital from Austro-Hungary$_t$, capital from France$_t$, capital from Germany$_t$, capital from UK$_t$ and capital from Germany/France$_t$ (with basegroup domestic sources) are dummy variables. The model represents a random-intercept three-level-model. The three different regressions refer to different basis concerning the calculation of fractality$_{t-10}$ ((*A*) 2,500 m, (*B*) 5,000 m and (*C*) 10,000 m). Distance to coast, elevation, ruggedness and distance to capital city are constant over time. Random effects parameters are displayed in log of standard deviations. Railway density $_{t-10}$ is ihs-transformed. Turkey is excluded since data only captures the European area of Turkey; * p<0.1; ** p<0.05; *** p<0.01.

Table 6: Linear mixed model - city with spatial lag

Dependent variable:		Population growth rate $_t$ 1850-2000 (A)	(B)	(C)
Fixed effects:				
Micro:	Fractality $_{t-10}$	0.590***	0.404***	0.307***
		(0.160)	(0.0983)	(0.0723)
	Neighbours' fractality $_{t-10}$	4.388***	2.262***	1.477***
		(0.883)	(0.479)	(0.321)
	Population level $_{t-10}$	-0.622***	-0.632***	-0.632***
		(0.0500)	(0.0503)	(0.0503)
	Distance to coast	-0.241***	-0.244***	-0.251***
		(0.0571)	(0.0570)	(0.0569)
	Elevation	0.0906	0.0931*	0.0967*
		(0.0561)	(0.0560)	(0.0558)
	Ruggedness	-0.0792**	-0.0755**	-0.0770**
		(0.0362)	(0.0362)	(0.0360)
	International railway $_t$	-0.102	-0.105	-0.101
		(0.114)	(0.114)	(0.114)
	National railway $_t$	0.00339	-0.00201	-0.00393
		(0.119)	(0.119)	(0.119)
	Capital from Austro-Hungary $_t$	-0.362***	-0.365***	-0.371***
		(0.119)	(0.118)	(0.118)
	Capital from France $_t$	-0.827***	-0.834***	-0.836***
		(0.311)	(0.310)	(0.310)
	Capital from Germany $_t$	0.0152	0.00258	-0.00750
		(0.131)	(0.130)	(0.130)
	Capital from United Kingdom $_t$	0.432*	0.428*	0.419*
		(0.227)	(0.226)	(0.226)
	Capital from Germany/France $_t$	0.212	0.179	0.157
		(0.275)	(0.274)	(0.273)
	Distance to capital city	-0.372***	-0.364***	-0.358***
		(0.0438)	(0.0437)	(0.0436)
Macro:	WWI $_t$	-1.695***	-1.707***	-1.717***
		(0.154)	(0.154)	(0.155)
	WWII $_t$	-0.348***	-0.361***	-0.359***
		(0.106)	(0.106)	(0.106)
	Great Depression $_t$	-0.826***	-0.834***	-0.839***
		(0.103)	(0.103)	(0.103)
	Fall of Communism $_t$	-1.605***	-1.596***	-1.587***
		(0.101)	(0.101)	(0.102)
	Ottoman decline $_t$	-0.906***	-0.896***	-0.900***
		(0.176)	(0.176)	(0.176)
	Trend	-0.00246	-0.00288	-0.00308
		(0.00271)	(0.00279)	(0.00281)
	Constant	15.38***	16.18***	16.50***
		(5.038)	(5.170)	(5.193)
Random effects:				
	Country level	-0.765***	-0.767***	-0.767***
		(0.286)	(0.285)	(0.283)
	Between cities	-0.246***	-0.250***	-0.255***
		(0.0672)	(0.0672)	(0.0674)
	Within cites	0.540***	0.539***	0.539***
		(0.0125)	(0.0125)	(0.0125)
Countries		12	12	12
N		3935	3935	3935

Note: Standard errors in parentheses. Population level$_{t-10}$, distance to coast, elevation and ruggedness are ihs-transformed. International railway$_t$, and national railway$_t$ (both with basegroup other railways) as well as capital from Austro-Hungary$_t$, capital from France$_t$, capital from Germany$_t$, capital from UK$_t$ and capital from Germany/France$_t$ (with basegroup domestic sources) are dummy variables. The model represents a random-intercept three-level-model. The three different regressions refer to different basis concerning the calculation of fractality$_{t-10}$ ((A) 2,500 m, (B) 5,000 m and (C) 10,000 m). Distance to coast, elevation, ruggedness and distance to capital city are constant over time. Random effects parameters are displayed in log of standard deviations; * p<0.1; ** p<0.05; *** p<0.01.

Table 7: Linear mixed model - extended with spatial lag

Dependent variable:		Population growth rate $_t$ 1850-2000 (A)	(B)	(C)
Fixed effects:				
Micro:	Fractality $_{t-10}$	0.310**	0.225**	0.186**
		(0.157)	(0.0986)	(0.0733)
	Neighbours' fractality $_{t-10}$	3.402**	2.152**	1.503**
		(1.616)	(0.928)	(0.646)
	Population level $_{t-10}$	-0.238***	-0.248***	-0.254***
		(0.0481)	(0.0488)	(0.0490)
	Distance to coast	-0.222***	-0.230***	-0.238***
		(0.0516)	(0.0519)	(0.0522)
	Elevation	0.0952*	0.0996**	0.104**
		(0.0487)	(0.0489)	(0.0490)
	Ruggedness	-0.0732**	-0.0719**	-0.0732**
		(0.0308)	(0.0309)	(0.0309)
	International railway $_t$	-0.0617	-0.0588	-0.0512
		(0.114)	(0.114)	(0.114)
	National railway $_t$	0.152	0.149	0.146
		(0.120)	(0.120)	(0.120)
	Capital from Austro-Hungary $_t$	-0.475***	-0.489***	-0.503***
		(0.122)	(0.122)	(0.122)
	Capital from France $_t$	-0.868***	-0.886***	-0.907***
		(0.317)	(0.318)	(0.318)
	Capital from Germany $_t$	0.221*	0.194	0.175
		(0.127)	(0.128)	(0.129)
	Capital from United Kingdom $_t$	-0.0755	-0.102	-0.122
		(0.290)	(0.292)	(0.292)
	Capital from Germany/France $_t$	0.0767	0.0591	0.0440
		(0.268)	(0.268)	(0.268)
	Distance to capital city	-0.209***	-0.206***	-0.201***
		(0.0422)	(0.0423)	(0.0423)
Macro:	Railway density $_{t-10}$	0.464***	0.419***	0.391***
		(0.133)	(0.137)	(0.141)
	GDP per capita growth rate $_{t-10}$	0.0926***	0.0923***	0.0919***
		(0.0148)	(0.0148)	(0.0148)
	WWI $_t$	-1.795***	-1.791***	-1.785***
		(0.220)	(0.220)	(0.219)
	WWII $_t$	0.763***	0.750***	0.751***
		(0.164)	(0.164)	(0.164)
	Great Depression $_t$	-0.294	-0.292	-0.285
		(0.232)	(0.232)	(0.232)
	Fall of Communism $_t$	-1.075***	-1.066***	-1.061***
		(0.117)	(0.117)	(0.118)
	Ottoman decline $_t$	-0.690**	-0.685**	-0.684**
		(0.274)	(0.273)	(0.273)
	Trend	-0.0214***	-0.0222***	-0.0222***
		(0.00350)	(0.00363)	(0.00365)
	Constant	46.11***	47.58***	47.64***
		(6.497)	(6.710)	(6.753)
Random effects:				
	Country level	-0.0959	-0.101	-0.107
		(0.238)	(0.238)	(0.238)
	Between cities	-0.821***	-0.808***	-0.806***
		(0.145)	(0.143)	(0.143)
	Within cites	0.472***	0.471***	0.470***
		(0.0167)	(0.0168)	(0.0168)
Countries		11	11	11
N		2,347	2,347	2,347

Note: Standard errors in parentheses. Population level$_{t-10}$, distance to coast, elevation and ruggedness are ihs-transformed. International railway $_t$, and national railway $_t$ (both with basegroup other railways) as well as capital from Austro-Hungary$_t$, capital from France$_t$, capital from Germany$_t$, capital from UK$_t$ and capital from Germany/France$_t$ (with basegroup domestic sources) are dummy variables. The model represents a random-intercept three-level-model. The three different regressions refer to different basis concerning the calculation of fractality t-10 ((*A*) 2,500 m, (*B*) 5,000 m and (*C*) 10,000 m). Distance to coast, elevation, ruggedness and distance to capital city are constant over time. Random effects parameters are displayed in log of standard deviations. Railway density$_{t-10}$ is ihs-transformed. Turkey is excluded since data only captures the European area of Turkey; * p<0.1; ** p<0.05; *** p<0.01.

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Appendix

Table 8: List of countries

Abbreviation	*Country*
AL	Albania
AT	Austria
BA	Bosnia-Herzegovina
BE	Belgium
BG	Bulgaria
CH	Switzerland
CZ	Czech Republic
DE	Germany
DK	Denmark
EE	Estonia
ES	Spain
FI	Finland
FR	France
GR	Greece
HR	Croatia
HU	Hungary
IE	Ireland
IT	Italy
LT	Latvia
LV	Lithuania
ME	Montenegro
MK	Macedonia
NL	Netherlands
NO	Norway
PL	Poland
PT	Portugal
RO	Romania
RS	Serbia
SE	Sweden
SI	Slovenia
SK	Slovakia
UK	United Kingdom
XK	Kosovo

Source: Own illustration.

Formula to calculate growth rates:

$Average\ growth\ rate:\ growth\ rate\ of\ Y = (\frac{Y_t}{Y_{t-10}})^{\frac{1}{10}} - 1$

Country regressions

Table 9: Data availability (by decade)

Year	*No of obs*
1840	8
1850	9
1860	13
1870	14
1880	15
1890	15
1900	19
1910	19
1920	16
1930	16
1940	18
1950	18
1960	21
1970	28
1980	28
1990	28
2000	33
2010	33
Total	351

Source: The Maddison-Project (2013), HGISE (2015), own calculations.
Note: Obs: Observations.

Explanatory variables:

- GDP per capita growth rate $_t$: average growth rate of GDP per capita in real terms (from the Maddison Project Database)
- Railway density $_{t-10}$: average railway length in km per 1,000 km^2.
- Railway density growth rate $_{t-10}$: average growth rate of the railway length (km per 1,000 km^2)
- GDP per capita $_{t-10}$: GDP per capita in real terms (1990 Int. GK$) (from the Maddison Project Database)
- Dummy variables:
  - EU: period of participation of each member state, considering each enlargement wave AT (1990-2010), BE (1950-2010), BG (2000-2010), CY (2000-2010), CZ (2000-2010), DK (1970-2010), EE (2000-2010), FI (1990-2010), FR (1950-2010), DE (1950-2010), GR (1980-2010), HU (2000-2010), IE (1970-2010), IT (1950-2010), LT (2000-2010), LV (2000-2010), NL (1950-2010), PL (2000-2010), PT (1980-2010), RO (2000-2010), SK (2000-2010), SI (2000-2010), ES (1980-2010), SE (1990-2010), UK (1970-2010)
  - Communist: AL (1940-2000), BG (1940-1990), CZ (1940-1990), HU (1940-1990), PL (1940-1990), RO (1940-1990)
  - Yugoslavia: BA, HR, XK, ME, MK, SI, RS (for all 1940-2000)
  - Habsburg Empire: AT (1830-1920), BA (1880-1920), CZ (1830-1920), HR (1830-1920), HU (1830-1920), IT (1830-1870), ME (1830-1920), PL (1830-1920), RO (1830-1920), RS (1830-1920), SI (1830-1920), SK (1830-1920), UA (1830-1920)

- Ottoman Empire: AL (1830-1910), BA (1830-1880), BG (1830-1880), GR (1830), ME (1830-1880), MK (1830-1910), RO (1830-1880), RS (1830-1880), TR (1830-1920), XK (1830-1910)
- Romanov Empire: EE (1830-1920), FI (1830-1920), LV (1830-1920), LT (1830-1920), PL (1830-1920), UA (1830-1920)
- Balkan: AL, BG, BA, GR, HR, XK, ME, MK, RO, RS, SI, TR (time-invariant)

Table 10: Data availability (by country)

Country	*No of obs*
AL	8
AT	18
BA	5
BE	16
BG	8
CH	15
CZ	2
DE	16
DK	18
EE	2
ES	16
FI	16
FR	18
GR	17
HR	5
HU	12
IE	8
IT	18
LT	2
LV	2
ME	5
MK	5
NL	18
NO	18
PL	8
PT	14
RO	8
RS	5
SE	18
SI	5
SK	2
UK	18
XK	5
Total	351

Source: The Maddison-Project (2013), HGISE (2015), own calculations.
Note: Obs: Observations.

Table 11: Descriptive statistics of variables (country level)

Variable	*Obs*	*Mean*	*SD*	*Min*	*Max*
GDP per capita growth rate	351	1.84	1.92	-3.25	10.32
Railway density	351	41.91	34.53	0	140.02
ihs-Railway density	351	3.82	1.45	0	5.63
Railway denstiy growth rate	321	2.62	7.65	-3.87	57.67

Source: The Maddison-Project (2013), HGISE (2015), own calculations.
Note: Obs: observations; SD: standard deviation.

Table 12: Explanatory dummy variables (country level)

Variable	*1*	*0*	*Total*
EU	67	284	351
Communist	23	328	351
Yugoslavia	28	323	351
Habsburg Empire	20	331	351
Ottoman Empire	2	349	351
Romanov Empire	9	342	351

Source: The Maddison-Project (2013), HGISE (2015), own calculations.

City regressions

Explanatory Variables:

- City level
  - Fractality is a measure to capture the railway density/coverage within a defined region around the city (A) refers to an outer ring around each city at 2.5 km, (B) 5 km and (C) 10 km (from HGISE). See section *'Data'*.
  - Distance to coast is a straight line between each city and the coast (in km) (from HGISE).
  - Elevation represents the altitude of each city (in m) (from HGISE).
  - Ruggedness is an index to quantify topographic heterogeneity (from HGISE).
  - Hierarchy of railway line: characteristic of the nearest line of each city (from HGISE).
    - International railway refers to a dummy for railways representing connections between countries or main ports.
    - National railway concerns main national railways which connect main national cities.
    - basegroup regards Secondary railway captures other railways
  - Origin of capital financing railway construction: nationality of promoters of the nearest railway of each city (from HGISE)
    - Capital from France captures promoters from France.
    - Capital from Germany captures promoters from Germany.
    - Capital from UK captures promoters from United Kingdom.
    - Capital from AH captures promoters form Austria-Hungary.
    - (basegroup regards promoters/capital from domestic sources)

- Country level
  - Railway density $_{t-10}$: average railway length in km per 1,000 km^2.
  - GDP per capita growth rate t: average growth rate of GDP per capita in real terms (from the Maddison Project Database).
  - Country dummy variables:
    * 1^{st} World War: 1910-1920
    * Great Depression: 1920-1940
    * 2^{nd} World War: 1940-1950
    * Fall of Communism: 1990-2000 (all countries with exception of TR and GR)
    * Ottoman decline[17] : 1850-1860, 1880-1900 (GR, TR), 1870-1880 (TR, RO), 1900-1910 (AL, BG, GR, MK, TR, XK)

Table 13: Data availability (by decade)

Year	*No of obs*
1860	39
1870	46
1880	59
1890	91
1900	112
1910	160
1920	173
1930	193
1940	292
1950	374
1960	410
1970	446
1980	475
1990	514
2000	551
Total	3,935

Source: HGISE (2015), own calculations.
Note: Obs: Observations.

17 This dummy captures periods in which more than 4% of the cities in a country reveal a negative population growth rate and refer to struggles in the wake of the Ottoman Empire's decline. The periods correspond to the Epirus revolt (1854), the Russo-Turkish War (1977-1878), the Greco-Turkish War (1897), the Albanian Revolt (1910) and the Macedonian Struggle (1904-1908).

Table 14: Data availability (by country)

Country	*No of obs*
AL	102
BA	150
BG	739
GR	517
HR	215
ME	61
MK	127
RO	1,124
RS	655
SI	65
TR	121
XK	59
Total	3,935

Source: HGISE (2015), own calculations.
Note: Obs: Observations.

Table 15: Explanatory dummy variables (city level)

Variable	*1*	*0*	*Total*
International railway	2,107	1,828	3,935
National railway	1,142	2,793	3,935
Capital from Austro-Hungary	1,054	2,881	3,935
Capital from France	89	3,846	3,935
Capital from Germany	527	3,408	3,935
Capital from United Kingdom	185	3,750	3,935
Capital from Germany/France	124	3,811	3,935

Source: HGISE (2015), own calculations.

Table 16: Descriptive statistics of variables (city level)

Variable	*Obs*	*Mean*	*SD*	*Min*	*Max*
Population growth	3,935	1.51	2.07	-16.54	17.92
Population level	3,935	47,059	183,038	600	6,629,431
ihs-Population level	3,935	10.68	0.95	7.09	16.4
Fractality (A)	3,935	0.34	0.3	0	0.92
Fractality (B)	3,935	0.68	0.52	0	1.62
Fractality (C)	3,935	1.03	0.72	0	2.31
Distance to coast	3,935	193.22	145.28	0.08	601.02
ihs-Distance to coast	3,935	5.2	1.83	0.08	7.09
Elevation	3,935	220.29	205.39	1.57	1,145.39
ihs-Elevation	3,935	5.59	1.13	1.23	7.74
Ruggedness	3,935	1,335.23	4,459.37	2.62	22,453.91
ihs-Ruggedness	3,935	5.12	1.87	1.69	10.71
Distance to capital	3,935	178.15	116.32	0	464.9
ihs-Distance to capital	3,935	5.46	1.32	0	6.83
Railway density	2,347	28.14	12.85	0	52.15
ihs-Railway density	2,347	3.83	0.8	0	4.65
GDP per capita growth rate	2,347	2.49	2.65	-2.32	7.13

Source: The Maddison-Project (2013), HGISE (2015), own calculations.
Note: Obs: observations; SD: standard deviation.

Table 17: Linear mixed model - city with spatial lag (domestically distance-based)

Dependent variable:		Population growth rate $_t$ 1850-2000 (A)	(B)	(C)
Fixed effects:				
Micro:	Fractality $_{t-10}$	0.689***	0.474***	0.360***
		(0.155)	(0.0936)	(0.0679)
	Neighbours' fractality $_{t-10}$	2.510***	1.293***	0.899***
		(0.537)	(0.287)	(0.191)
	Population level $_{t-10}$	-0.632***	-0.644***	-0.644***
		(0.0498)	(0.0500)	(0.0499)
	Distance to coast	-0.205***	-0.214***	-0.220***
		(0.0569)	(0.0568)	(0.0568)
	Elevation	0.0605	0.0656	0.0690
		(0.0559)	(0.0557)	(0.0556)
	Ruggedness	-0.0860**	-0.0822**	-0.0836**
		(0.0362)	(0.0361)	(0.0359)
	International railway t	-0.115	-0.118	-0.113
		(0.114)	(0.114)	(0.114)
	National railway $_t$	-0.00352	-0.00468	-0.00500
		(0.119)	(0.119)	(0.119)
	Capital from Austro-Hungary $_t$	-0.260**	-0.279**	-0.285**
		(0.118)	(0.118)	(0.118)
	Capital from France $_t$	-0.767**	-0.787**	-0.775**
		(0.311)	(0.311)	(0.310)
	Capital from Germany $_t$	0.0548	0.0489	0.0442
		(0.131)	(0.131)	(0.130)
	Capital from United Kingdom $_t$	0.458**	0.467**	0.470**
		(0.228)	(0.228)	(0.228)
	Capital from Germany/France $_t$	0.0599	0.0488	0.0308
		(0.274)	(0.273)	(0.272)
	Distance to capital city	-0.374***	-0.367***	-0.361***
		(0.0438)	(0.0437)	(0.0436)
Macro:	WWI $_t$	-1.603***	-1.618***	-1.640***
		(0.150)	(0.150)	(0.150)
	WWII $_t$	-0.287***	-0.301***	-0.310***
		(0.103)	(0.103)	(0.103)
	Great Depression $_t$	-0.744***	-0.755***	-0.770***
		(0.0975)	(0.0975)	(0.0975)
	Fall of Communism $_t$	-1.735***	-1.721***	-1.703***
		(0.0920)	(0.0920)	(0.0923)
	Ottoman decline $_t$	-0.899***	-0.889***	-0.897***
		(0.177)	(0.176)	(0.176)
	Trend	0.00276	0.00232	0.00164
		(0.00195)	(0.00197)	(0.00197)
	Constant	5.969	6.821*	8.065**
		(3.676)	(3.706)	(3.715)
Random effects:				
	Country level	-0.602**	-0.607**	-0.592**
		(0.284)	(0.281)	(0.278)
	Between cities	-0.257***	-0.261***	-0.267***
		(0.0681)	(0.0681)	(0.0682)
	Within cites	0.541***	0.540***	0.539***
		(0.0125)	(0.0125)	(0.0125)
Countries		12	12	12
N		3,935	3,935	3,935

Note: Standard errors in parentheses. Population level$_{t-10}$, distance to coast, elevation and ruggedness are ihs-transformed. International railway$_t$, and national railway$_t$ (both with basegroup other railways) as well as capital from Austro-Hungary$_t$, capital from France$_t$, capital from Germany$_t$, capital from UK$_t$ and capital from Germany/France$_t$ (with basegroup domestic sources) are dummy variables. The model represents a random-intercept three-level-model. The three different regressions refer to different basis concerning the calculation of fractality$_{t-10}$ ((*A*) 2,500 m, (*B*) 5,000 m and (*C*) 10,000 m). Distance to coast, elevation, ruggedness and distance to capital city are constant over time. Random effects parameters are displayed in log of standard deviations. For the calculation of W we consider the distance between cities in the same country; * p<0.1; ** p<0.05; *** p<0.01.

Table 18: Linear mixed model - extended with spatial lag (domestically distance-based)

Dependent variable:		Population growth rate $_t$ 1850-2000		
		(A)	(B)	(C)
Fixed effects:				
Micro:	Fractality $_{t-10}$	0.344**	0.264***	0.230***
		(0.157)	(0.0977)	(0.0724)
	Neighbours' fractality $_{t-10}$	-0.266	-0.00885	0.270
		(1.447)	(0.796)	(0.541)
	Population level $_{t-10}$	-0.236***	-0.248***	-0.257***
		(0.0479)	(0.0484)	(0.0485)
	Distance to coast	-0.199***	-0.203***	-0.206***
		(0.0504)	(0.0504)	(0.0506)
	Elevation	0.0838*	0.0861*	0.0873*
		(0.0481)	(0.0482)	(0.0483)
	Ruggedness	-0.0701**	-0.0689**	-0.0709**
		(0.0307)	(0.0307)	(0.0307)
	International railway $_t$	-0.0764	-0.0772	-0.0747
		(0.114)	(0.114)	(0.114)
	National railway $_t$	0.143	0.141	0.141
		(0.119)	(0.119)	(0.119)
	Capital from Austro-Hungary $_t$	-0.412***	-0.423***	-0.430***
		(0.118)	(0.118)	(0.118)
	Capital from France $_t$	-0.866***	-0.890***	-0.901***
		(0.315)	(0.316)	(0.316)
	Capital from Germany $_t$	0.248*	0.239*	0.237*
		(0.127)	(0.127)	(0.128)
	Capital from United Kingdom $_t$	-0.0577	-0.0544	-0.0574
		(0.288)	(0.288)	(0.288)
	Capital from Germany/France $_t$	0.0301	0.0130	-0.00831
		(0.266)	(0.266)	(0.265)
	Distance to capital city	-0.198***	-0.195***	-0.194***
		(0.0421)	(0.0420)	(0.0420)
Macro:	Railway density $_{t-10}$	0.591***	0.570***	0.526***
		(0.132)	(0.136)	(0.140)
	GDP per capita growth rate $_{t-10}$	0.0939***	0.0938***	0.0932***
		(0.0149)	(0.0149)	(0.0149)
	WWI $_t$	-1.793***	-1.790***	-1.784***
		(0.220)	(0.220)	(0.220)
	WWII $_t$	0.799***	0.800***	0.807***
		(0.164)	(0.164)	(0.164)
	Great Depression $_t$	-0.282	-0.279	-0.275
		(0.232)	(0.232)	(0.232)
	Fall of Communism $_t$	-1.137***	-1.138***	-1.142***
		(0.114)	(0.114)	(0.114)
	Ottoman decline $_t$	-0.666**	-0.664**	-0.664**
		(0.275)	(0.274)	(0.274)
	Trend	-0.0172***	-0.0172***	-0.0174***
		(0.00295)	(0.00295)	(0.00294)
	Constant	38.26***	38.31***	38.68***
		(5.501)	(5.494)	(5.479)
Random effects:				
	Country level	-0.127	-0.110	-0.0807
		(0.245)	(0.244)	(0.245)
	Between cities	-0.857***	-0.852***	-0.849***
		(0.152)	(0.151)	(0.150)
	Within cites	0.475***	0.475***	0.474***
		(0.0167)	(0.0167)	(0.0167)
Countries		11	11	11
N		2,347	2,347	2,347

Note: Standard errors in parentheses. Population level$_{t-10}$, distance to coast, elevation and ruggedness are ihs-transformed. International railway$_t$, and national railway$_t$ (both with basegroup other railways) as well as capital from Austro-Hungary$_t$, capital from France$_t$, capital from Germany$_t$, capital from UK$_t$ and capital from Germany/France$_t$ (with basegroup domestic sources) are dummy variables. The model represents a random-intercept three-level-model. The three different regressions refer to different basis concerning the calculation of fractality$_{t-10}$ ((*A*) 2,500 m, (*B*) 5,000 m and (*C*) 10,000 m). Distance to coast, elevation, ruggedness and distance to capital city are constant over time. Random effects parameters are displayed in log of standard deviations. Railway desnsity$_{t-10}$ is ihs-transformed. Turkey is excluded since data only captures the European area of Turkey. For the calculation of W we consider the distance between cities in the same country; * p<0.1; ** p<0.05; *** p<0.01.