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A GIS analysis of the evolution of the railway network and population densities in England and Wales, 1851-2000

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Abstract

This paper links the development of urban settlements in England and Wales to the expansion of the railway. We assembled a dataset including the population of local civil parishes and operational railway lines and stations with annual detail from 1851 to 2000 and use GIS software to test whether the uneven geographic transformation of England and Wales is significantly related to access to new means of transportation, namely the newly established railway lines and stations. We find a dynamic relationship between population growth and transport infrastructure. We suggest the use of railway stations instead of kilometers of line as a more precise indication of access to rail. We find that rural and urban settlements were uneven, and very much linked to the opening of new rail stations.

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1. Introduction

From economic geography, we know that transportation costs, the spatial location of firms and urban nuclei are important to generate complementarities and economies of scale (Krugman, 1991). We also know that industrial hubs and cities are live events in the sense that they are subject to continuous interactions and changes. The future of research in economic geography is advocated to follow this direction (Thisse, 2009). Thus, the study of historical or dynamic economic geography is therefore fundamental to understanding the processes of change and evolution.

In the 19th century, railways would have helped to promote new areas and those with previous economic activity and the capacity for growth were particularly successful at attracting population. Atack *et al.* (2010) find that at least one half of the growth of urbanization in the mid-19th century American Midwest might be attributable to the arrival of the railways. The American case study is undeniably interesting given its economic and human geography impact. And what about the nation that rocked the beginnings of industrialization and the first arrival of the railway? Casson (2009) discusses the efficiency of the shape of the network; Bogart (2009) focuses on political factors; Gregory and Schwartz (2009) do a partial analysis for Wales; and Schwartz, Gregory and Thevenin (2011) make a comparison with France.

The aim of this paper is analyzing the uneven geographical transformation of England and Wales from 1851 to the present day, by means of following the evolution of the railway network alongside population growth. We ensemble a dataset including the population of local civil parishes and operational railway lines and stations with annual detail from 1851 to 2000. Then, we use spatial analysis methodologies, namely Geographical Information Systems (GIS). We develop a platform that we call the Historical Geographic Information System - Europe (HGISe) [1]. This is part of an information infrastructure designed to facilitate a step forward in our understanding of the emergence of modern Europe. The HGISe offers a spatiotemporal platform for the integration, visualization and analysis of European development over time. By using space or location as a means for combining and comparing data, HGISe promises to become a highly flexible, multi-disciplinary tool which can be employed over a wide academic area ranging from history and cultural studies to environmental sciences and

[1] HGISe refers to our research group. For more information, consult the HGISE web site, at the Universitat de Lleida. www.europa.udl.cat/hgise

transportation studies. This type of approach gives rise to a series of relevant conclusions within the economic history of the impact of railways and territorial inequalities.

2. Historical Background

The urbanization process in England and Wales began in the middle of the 19th century and finished –in demographical terms- at the time of the Second World War. In 1871, more than half of their population already lived within the boundaries of an agglomeration and in 1921 this percentage had risen to 80 percent.

During the period 1871-2001, the urban population of England and Wales increased to almost forty million. More than half of this growth occurred before 1911, coinciding with the Victorian Era and the Second Industrial Revolution. The optimization of agriculture and industrial production in factories allowed a dual process of demographic and economic agglomeration in the urban centres. An urban boom therefore resulted which went further than the simple spatial redistribution of the work force. This urban growth was subsequently consolidated during the interwar period. From 1911 to 1951, nine million more people settled within the boundaries of England and Wales's agglomerations.

Strong urban growth resulted in high urban population densities, disorganization, health problems, congestion and civil unrest. These caused generalized functional inefficiency which had a direct impact on the economic system. As a consequence, urban settlements such as London and Manchester followed a slower rhythm than other medium-sized cities and even rural areas during the demographic transition (Mumford, 1966).

But the liberal city was an urban space capable of rationalizing production processes and establishing new essential functional relationships between industry, transport infrastructures and the work force: there was a change from centripetal patterns of growth to a predominance of centrifugal ones. While *Haussmannisation* allowed the modernization of urban centres for new bourgeois usages, the *laissez faire* attitude transformed Great Britain's urban centres through an amalgam of competing uses.

Within this context, only the urban periphery remained insufficiently defined to accommodate innovation.

Although during the Victorian age urban settlements were clearly differentiated from rural ones due to their size and density, after the Second World War, the English territory was scattered with patches of urban uses. In this way, thread-like territorial patterns emerged along the coast and major transport routes, as did seemingly never-ending variable-density conurbations, dispersed urban settlements, ex novo New Towns and huge agglomerations.

In this sense, it is important to bear in mind the fact that the urban history of England and Wales has been closely linked to successive innovations in the means of transport, which have effectively shortened distances and increased the interaction between different population settlements. The first step was the implantation of a consolidated railway network which illustrated the magnitude of suburbanization prior to the First World War.

3. Data sources, treatment and methodology

The beginning of the real articulation of the railway network at the beginning of the 19th century coincides with the publication of the first reliable population censuses. Before, population counts were rough calculations gathered together from baptisms, marriages and buries. Total population head counts do not coincide with the regional breakup disaggregated numbers. Recall that members of the army, merchant marine, missioners, and others were excluded of local registers simply because they were outside Britain at the moment of the headcount.

The present work combines data from two different but complementary sources. On one hand, there are data relating to the distribution of population over space and time - gathered at the parish level. Demographic data has been used as an indicator of urban, social, economic, functional and structural processes of British history (Law, 1967; Moriconi, 1994). On the other, there are the data relating to the evolution of the rail network that provided transport services for passengers and merchandise.

Population data comes from historical censuses tracks. The English and Welsh census are available at 10 year intervals from 1801 through to the present day –except 1941 due

to the Second World War. However, data published before 1851 has been omitted from current study because its lack of reliability. Census data has been used across the entire period at the maximum disaggregation level available: that of the civil parish. The civil parish is the bottom rung of the British local government hierarchy, below districts and county councils, and made up the smallest unit of census data disaggregation. Specifically, data at the parish level gives a fine granularity as there were from 15,000 to 17,000 individual units depending on the year.

Any diachronic analysis of Great Britain's historic census data involves significant problems due to the changes that have taken place in the boundaries of spatial units used for reference. In the first modern censuses, no-one was particularly worried about making data comparable over time because - from the point of view of innovation - the main emphasis was on optimizing the system so that it could collect demographic data from year to year. Although the civil parish system is stable, there are many changes at the micro-scale that impede direct comparison over time, such as network density and rail accessibility (Winchester, 1990). In other cases, the system used has been completely different, as has occurred with censuses conducted since 1974.

Eventually, the data used were taken from the parish-level tables for the censuses of 1871 to 1971. These were all available linked to polygons within the Great Britain Historical Geographical Information System (GBHGIS), providing a spatial location for each parish. Over the total 100 year period the GBHGIS records the approximately 20,000 changes to parish boundaries that occurred as changes to the polygon boundaries recorded in the GIS software. Although these changes were significant, the number of parishes remains roughly constant at between 15,000 and 17,000 for most of the century. It was therefore felt that this data could be used in its raw form. However, subsequent years had been "re-districted" onto a single set of boundaries such as the parishes as arranged in 1971 (Gregory and Ell, 2005) because the parish system was abolished.

Population data has been subsequently treated to form urban units according to quantitative and demographic criteria. Urban agglomerations are defined *as intensely populated urban conglomerates that tend to persist over time as important social, political and economic bodies*. Their demographic relevance is therefore related to the concentration of economic activities, political power and knowledge. In this sense, it is important to underline the connections that the concept of population agglomeration has

with the location theories of Ullman (1956), bid-rent theories (Alonso, 1964; Mills, 1967; Murth, 1969), and economies of scale and agglomeration (Fujita and Thisse, 2002).

Finally, data referring to the railway network were taken from historical map sources; mainly from Coronel Cobb's atlas. Although railway map sources present fewer controversies, a substantive amount of work was required to digitalize all railway lines and stations in England and Wales. The research project HGISe carried out the exhaustive task of compiling and digitalizing data relating to both railway lines and their attributes (year of opening and/or closure, type of track, mileage) yearly for the period 1800- 2000.

As far as methodology is concerned, we have made use of GIS software and statistical analysis programs as the main tools. Using GIS makes it possible to store, handle, analyze, and quantify data and identify patterns and deal with all kinds of geo-referenced information. Specifically, we overlapped the location of railway lines and stations with the inhabitants' demographic information of a given place. Taking also into account its opening and closure years, it has been possible to draw some spatio-temporal tendencies and dynamics detailed below.

4. Results

4.1. The inverted-U shape and the two phases

The following graphs illustrate the co-evolution of the railway lines and stations in England and Wales from 1861 to 2001, one decade up or down depending on data availability. Both figures 1 and 2, corresponding respectively to railway lines and stations, depict an inverted-U shape when plotted against growing population numbers. This means that there are two clearly differentiated phases in the expansion of the railway in England and Wales. The first phase can be called "expansionary" phase and it is characteristic of a growing economy, while developing its industrial sector.

The railway is the key to linking new industrial hubs in this first phase, which continues in England and Wales until total population reaches a certain threshold. The process of raising the number of train stations seems to saturate at the point where total population

Figure 1

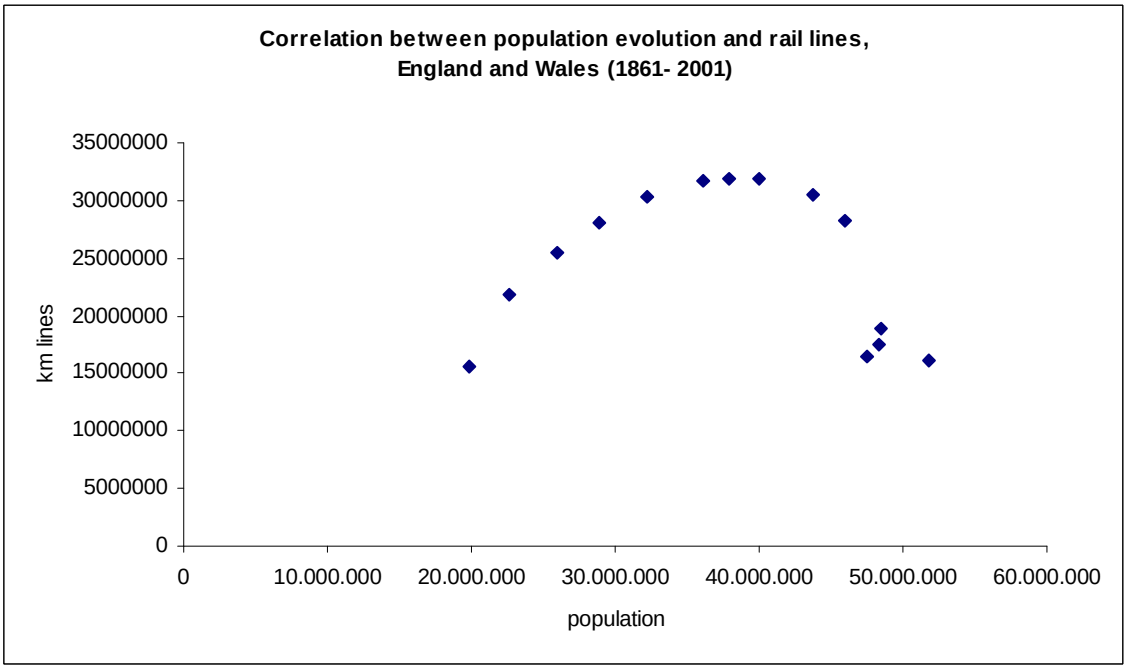
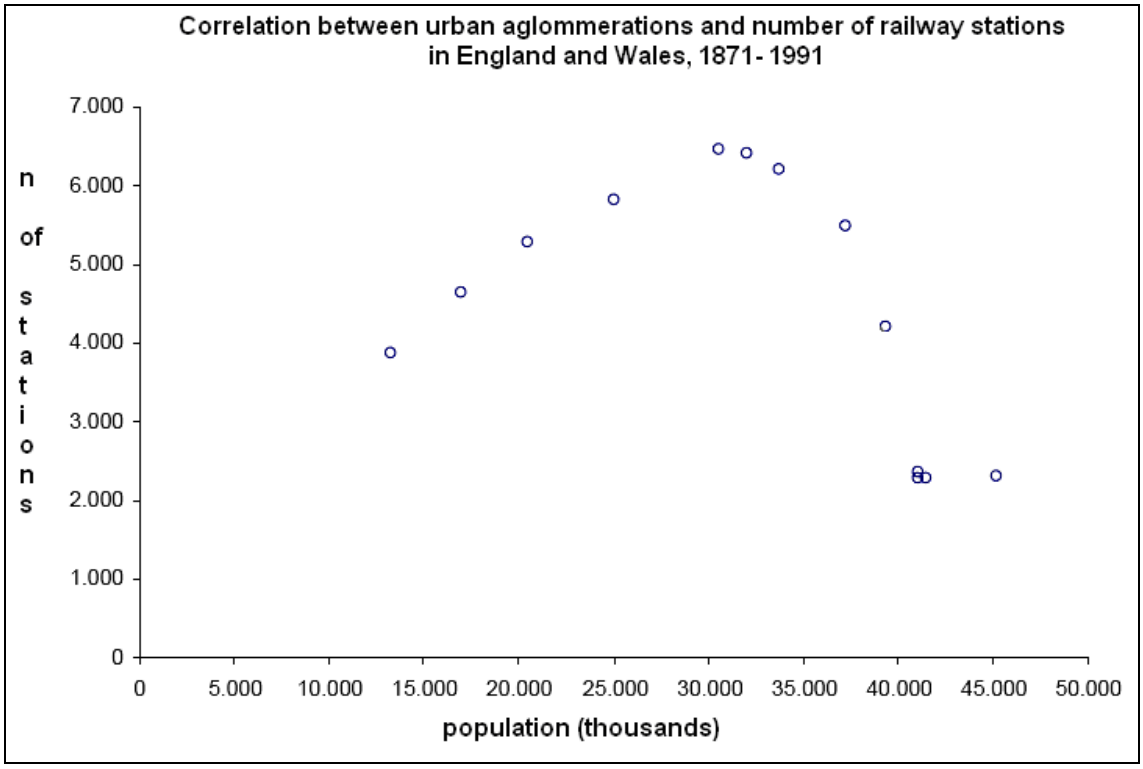


Figure 2



amounts to 30 million people (at the turn of the 20th century), while adding more kilometers of lines saturates where total population reaches around 40 million people, actually much later, right before the Second World War. From the saturation points onwards, the British railway network starts to shrink. This is the second phase, which we can call "restrictive" phase. If the British rail system built up more than three thousand stations in thirty years in its early history, it equally rapidly stagnated, and some stations were closed down.

The restrictive phase is characterized by increasing locative efficiency. Once reached the saturation point, the railway network not only does not need to expand further in order to observe growing population but it is even shrinking, in order to achieve greater efficiency. The turning point can be pinpointed in parliamentary debates that lead to the Beeching Act of 1963. In this law the government dictated major line and station cuts that would turn effective in the subsequent years, as is reflected in figures 1 and 2. Total length of operative railway lines was reduced to half its total length at the peak, mid-20th century. The reduction in the number of stations was even more drastic, falling from above 6,000 to around 2,000 stations. This might be linked to the generalization of the automobile as complementary means of transportation. It is remarkable that we do not observe these massive closures in other countries, which reveals the fact that the British network was one of the densest before the closures.

4.2. Changing patterns: Evolution of active lines

In spite of the construction of the 112-mile London and Birmingham railway in 1838, it was not until the 1840s that the country experienced the first railway mania. Up to then, many cities and regions were hostile to the new means of transport, delaying its expansion. Later, England and Wales developed a national system that gained momentum in dramatic fashion during the 1850s and 1860s. Figure 3 shows the evolution of the ever opened railway stations since 1811, while figure 4 details the total opening of lines per year. From here, it stands clear that maximum effervescence of the "expansionary" phase took place during the second half of the 19th century. Almost one hundred stations were opened per decade until the system reached its ceiling in 1871 with 3226 stations. In less than forty years the English and Welsh rail system became complete, structured and mature.

Figure 3

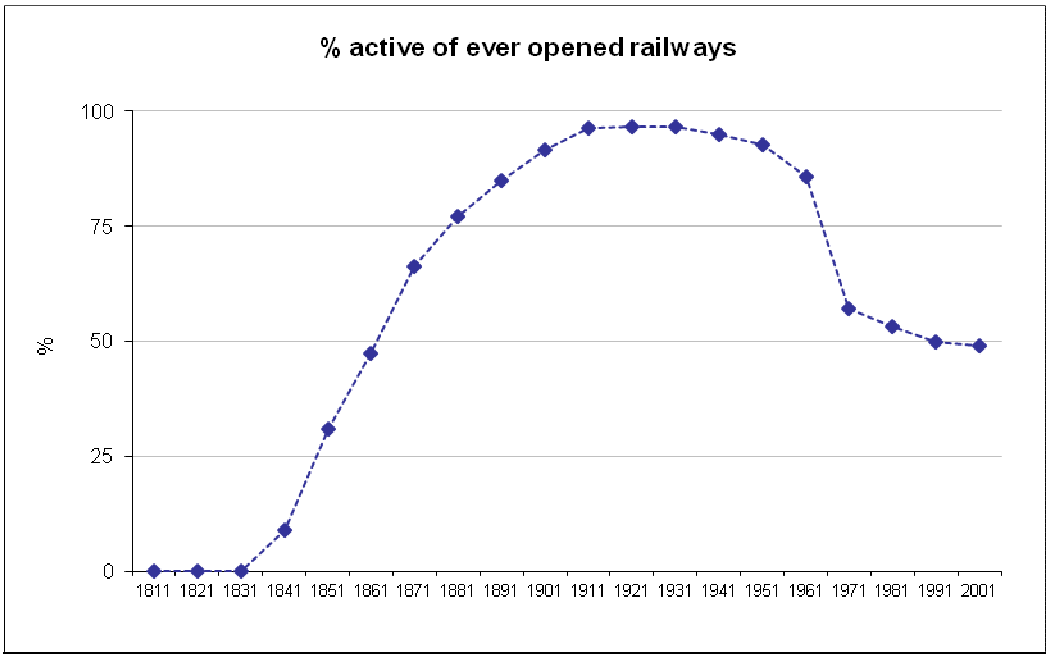
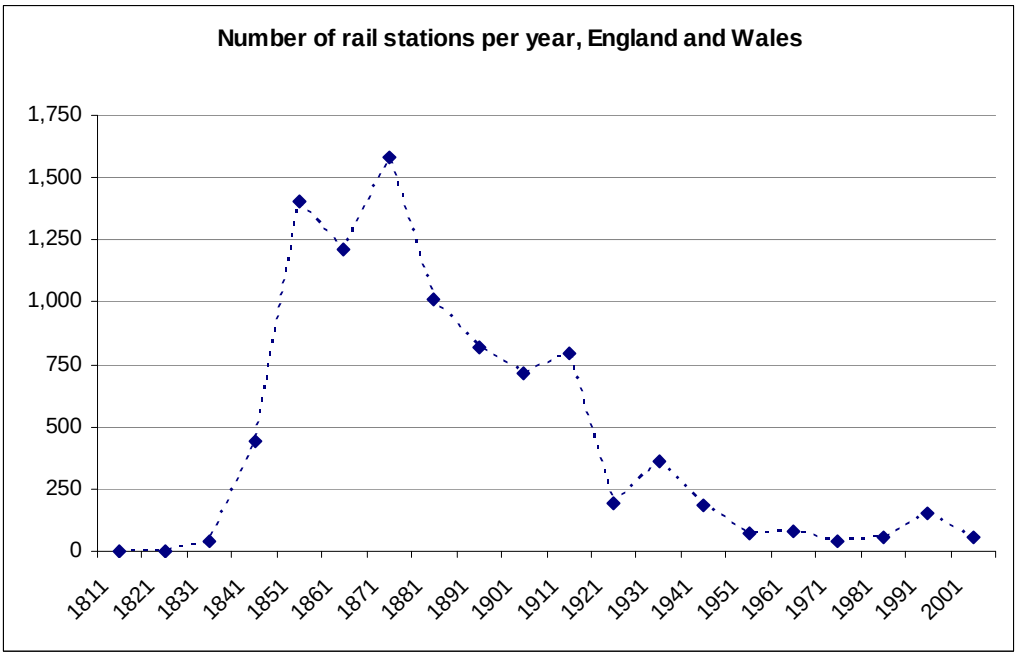


Figure 4



After that date, new construction was concentrated on extending railways by branch lines and filling gaps in the map. The network reaches a satisfactory level of coverage in the first decades of the 20th century, when population keeps growing while the number of lines and stations grow at a much slower pace. Once reached the saturation phase around 1940, about 50 percent of the total number of stations ever opened where closed in half a century. From 1871 to 1951 it closed 620 stations; the same numbers of rail accesses were closed in the following decade. Thus, we see that the "restrictive" phase is characteristic of the second half of the 20th century. With the closure of 791 more stations during the 1970s, the rail system has remained until the present with the same number of railway accesses as the 1850s.

Overall, there are two parallel processes taking place in the evolution of the British railway network. One refers to growing numbers of total population shown above as railway expands, which evidences the removal of possible railway bottlenecks. The other undergoing pattern once reached the saturation point is the subsequent and systematic closure of lines and stations, possibly linked to the rise of other means of transportation.

4.3. Access to rail: Urban versus rural divide

Before reflecting on why stations were placed in urban or rural settlements we need to understand the purposes of having a certain location connected to the railway network. We need to take into account that railways were conceived to link the main nodes of production, distribution and consumption. Therefore, arguably the English and Welsh railway system fits, broadly speaking, in the structure and hierarchy of the urban system. The probability of a given place to have enough importance to determine the creation or prolongation of a rail line, or the opening of a station, would be determined by its demographic weight as far as it would be a potential market and production centre. Lines initially build to bridge the distance between any two distant nuclei ended up opening intermediate stations, profiting from the costs of setting up a new line. However, and as a consequence of it, some places could be connected independently to its population as they take the advantage of its location.

Figure 5

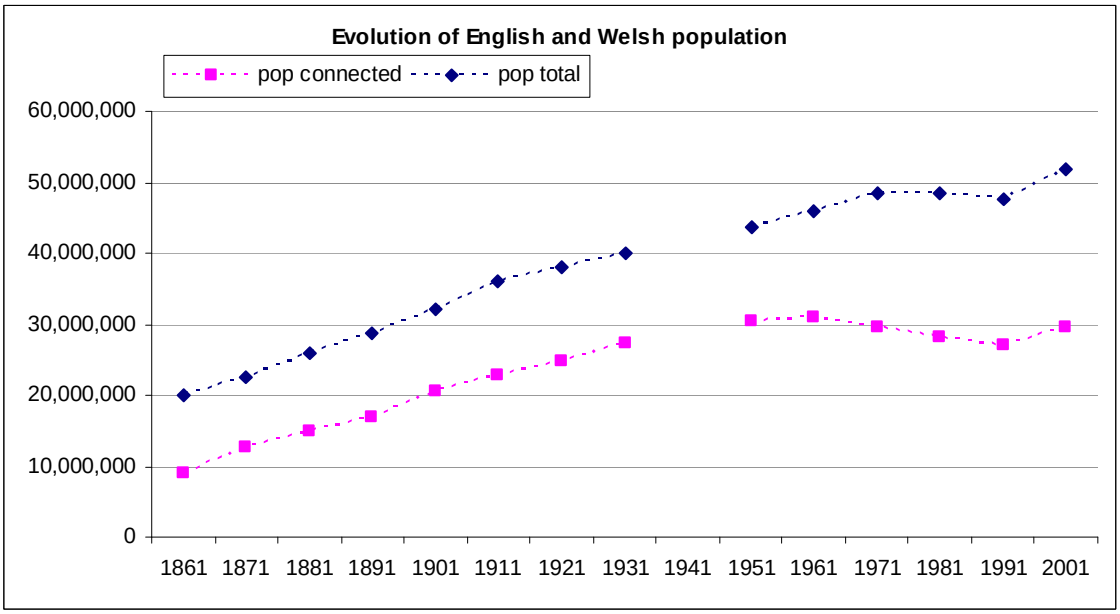


Figure 6

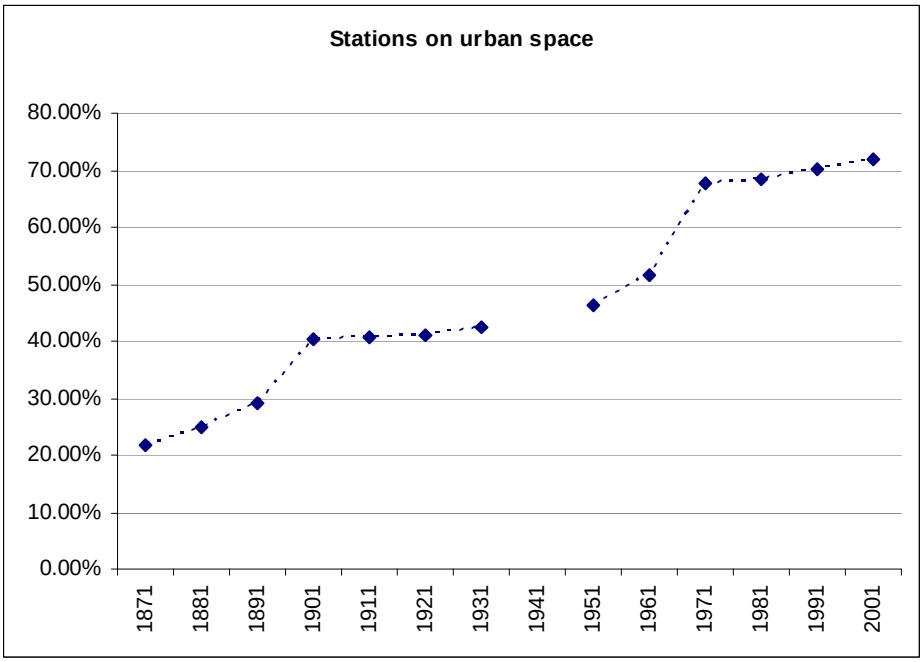


Figure 5 depicts the total number of English and Welsh population with direct access to the railways along history, and compares it to total population. The percentage of population with direct access to rail rises significantly along the 19th century, and up to around 70 percent in year 1931. The coefficient of correlation of population connected to the network and total population from 1861 (after the expansionary boom) all the way up to the Second World War is 0.846. Later on, the processes of closure of stations together with the generalization of the automobile reduce rail accessibility to 1871 levels.

Figure 6 shows that by 1871 the majority of train stations were located in rural space. This is because the main urban agglomerations were few, distant and isolated. The railway lines that linked them were long and with numerous intermediate stations.

Railways rapidly set in motion powerful currents of national integration by more rapid communication of people and ideas, and by communicating production, consumption and distribution places (Langton, 1984; Shaw-Taylor, 2009). Consequences of the establishment of intermediate stations run from labor migration to consolidation of the rural economy and homogenization of the access to information and expansion of the urban model. It transformed the English market, with the decline of local and regional loyalties in favor of a more open economy (Clark, 2000). This epitomizes a suggestion that economic linkages between far away locations were becoming more important as transport improved, amongst other factors.

How have these characteristics evolved over time? Along the period under study the number of stations on urban space has doubled, reaching 70 percent in year 2001. This rise in the number of urban stations has been heterogeneously distributed in time, mainly occurring during the post- Second World War years, and especially in England.

The appearance of the first motor vehicles made it possible to reach out beyond the pedestrian scale of these examples of suburbia that predated the “integrated technology of decentralization” of the 1920s, while as their use became more generalized – particularly from the 1960s onwards-, the spatial restrictions on urban expansion were definitively overcome (Mitchell, 1999).

Industrial delocalization, the internalization of productive processes, the shift to tertiary and quaternary sector economies, the creation of the international society (Castells, 1999), and the emergence of Global Cities and Edge Cities, all tended to speed up the

process of urban sprawl. Moreover, the progressive intensification of suburban processes and the tertiarization of the centres resulted in a network city based on relationships between distant elements and parts. The spatial fissure between the productive and homework spheres generated a growing, fragmented and irregular city in which the individual needed more and more time to move to ever more distant points.

5. Conclusions

Data relating to both railway networks and population have been included in a GIS platform. In this case, GIS helped us compiling, analyzing and quantifying data, recognizing patterns and treating the information after a previous task of geo-referencing undertaken under the HGISe project. In this way, the project carried out an exhaustive task of compiling and digitalizing data relating to both railway lines and their attributes (year of opening and closure if any, type of track, etc.) at ten year intervals for the period 1800- 2000.

The number of lines and stations has been following an evolution like that of a life animal, and it is worth studying. We distinguish two phases or periods in the history of the British rail. Since the beginning of the 19th with the opening of the first railways lines, kilometers of new lines and stations were being inaugurated for the first time all the way through the 19th century and well entered into the 20th century. Population grew steadily accordingly during this period. The expansion phase took place mainly in the second half of the 19th century, comprising a period running from the 1840s to the 1910s. However, this happened not always at the same pace.

20th century British railway history has been more characterized by the closing of numerous inefficient lines and sparely used stations than by the opening of new lines. Still, population growth was taking place simultaneously at a much smoother and constant pace, thanks to the generalization of other means of transportation, mainly the automobile.

Opening of new lines was uneven in the urban/rural divide. Rural and urban developments differed considerably. We map all new lines and stations and observe any population shocks following the opening of the railway. We find some evidence of the co-evolution of new railway lines and stations and population increase shocks. Up to what extent where railway expansion and urbanization linked to one another remains

unproven. Either changes in the distribution of population and economic development cannot be proven to be a direct consequence of the implementation of railways. Still, there is a dynamic relationship between population growth and transport infrastructure. We use population access to railway stations instead of kilometers of line as a more precise indication of access to rail. We find that rural and urban settlements were uneven, and very much linked to the opening of new rail stations.

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