

Pasidis, Ilias-Nikiforos; Garcia-López, Miquel-Àngel; Viladecans-Marsal, Elisabet

## Conference Paper

# Express delivery to the suburbs. Transport Infrastructure and European cities.

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# **Express delivery to the suburbs. Transport Infrastructure and European cities.**

(Preliminary revision)

**Miquel-Àngel Garcia-López<sup>†</sup>**

*Universitat Autònoma de Barcelona and Institut d'Economia de Barcelona*

**Ilias Pasidis<sup>§</sup>**

*Universitat de Barcelona and Institut d'Economia de Barcelona*

**Elisabet Viladecans-Marsal<sup>§</sup>**

*Universitat de Barcelona and Institut d'Economia de Barcelona*

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**ABSTRACT:** The main goal of this paper is to provide evidence for the causal effect of the highway and railway infrastructure on the suburbanization of population in European cities. This is considered a major issue in Europe, which has never been studied before at this scale. We constructed a unique population and transport infrastructure dataset covering 579 cities from 29 European countries during the period 1961-2011. We have included different measures of highways and railways on suburbanization and we have estimated their joint effect using a panel IV approach. Our main specification, where we jointly estimate the effect of highways and railways, suggest that an additional highway ray displaced approximately 6% of the central city population in European cities during the period 1961-2011 on average, whereas the same estimate for radial railways was roughly 2%. We will also employ the heterogeneity of the European regions and cities in order to detect different patterns of the same effect based on regional and city characteristics. The findings of this paper are novel and yield valuable insights for the European transport and regional policies.

**Key words:** suburbanization, cities, Europe, highways, railways, transport infrastructure, history, geography.

**JEL classification:** R4, O4

<sup>†</sup>Corresponding author. Department of Applied Economics, Universitat Autònoma de Barcelona, Edifici B, Facultat d'Economia i Empresa, 08193 Cerdanyola del Vallés, Spain (e-mail: [miquelangel.garcia@uab.cat](mailto:miquelangel.garcia@uab.cat); phone: +34 93 581 4584; website: <http://gent.uab.cat/miquelangelgarcialopez>).

<sup>§</sup>Department of Public Economics, Universitat de Barcelona, Avinguda Diagonal 690, 08034 Barcelona, Spain (e-mail: [ipasidis@ub.edu](mailto:ipasidis@ub.edu); phone: +34 68 403 7346).

<sup>§</sup>Department of Public Economics, Universitat de Barcelona, Avinguda Diagonal 690, 08034 Barcelona, Spain (e-mail: [eviladecans@ub.edu](mailto:eviladecans@ub.edu); phone: +34 93 403 4825; website: <http://sites.google.com/site/eviladecans>).

# 1 Introduction.

Transportation technologies and infrastructure shape cities and dictate urban form (Glaeser and Kahn, 2004). Transportation improvements affect commuting patterns by reducing the transport costs that the principal city agents face in a city. Via this mechanism, urban economic theory predicts that transport infrastructure improvements may facilitate the suburbanization process. In this paper, we will test this hypothesis by estimating the effect of highways and railways on the *suburbanization*<sup>1</sup> of European cities in the period 1961-2011.

Suburbanization and urban sprawl may have important repercussions. Some of the the consequences that have been highlighted in the literature are the greater resource consumption and CO<sub>2</sub> emissions (Glaeser and Kahn, 2010), the inefficient supply of public goods (Carruthers and Ulfarsson, 2003) or the decline in social interaction and the increase in social and ethnic segregation (Glaeser and Kahn, 2004), among others. Although the literature is still inconclusive about the overall effect and the exact determinants of suburbanization and urban sprawl, these interrelated processes are regarded as major issues in Europe.

Even though Glaeser and Kahn (2004) claimed that "the primary social problem associated with sprawl is the fact that some people are left behind because they do not earn enough to afford the cars that this form of living requires", EU and many academics in Europe look at sprawl from a different standpoint. This is reflected in *Europe 2020* strategy goals, which focuses on; the reduction of CO<sub>2</sub> emissions and the increase in energy efficiency; fighting social exclusion; education and R&D. Even though the latter two seem to be irrelevant in this discussion, they express a main opposition to the usual allocation of EU funding, which could be argued that favours "hard infrastructure" (e.g. highways) against "soft infrastructure" (e.g. human capital) investments.

Europe has a series of unique characteristics that make it a very interesting case to study. First of all, there has been a huge development of the transport infrastructure, partly financed by the EU, whose transport policy aims at expanding the transport network throughout Europe. The total length of the highway network alone increased from approximately 300 km in 1961 to approximately 50,000 km in 2011. These developments were largely determined by the allocation of the EU funding, which favours the poorest regions. Rail received only a small part of the investment in infrastructure by Member States, since road infrastructure has taken the lion's share. Nevertheless, rail's share has increased during the last years<sup>2</sup> reflecting the EU objectives for a *Single European Railway Area* (European Commission, 2010).

Although urban sprawl and suburbanization have been studied extensively in the US (Brueckner, 2000, 2001; Glaeser and Kahn, 2004; Baum-Snow, 2007a), studies for Europe are still very scarce. Despite the fact that various recent papers, including Batty et al. (2003), Phelps and Parsons (2003), Couch et al. (2008) and Pirotte and Madre (2011), focus on urban sprawl within particular regions or cities, only Patacchini and Zenou (2009), Arribas-Bel et al. (2011) and Oueslati et al.

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<sup>1</sup>By suburbanization, we refer to the *relative suburbanization* i.e. when the population of the suburbs grows more than the population of the central city.

<sup>2</sup>Almost 30% (€23.6 billion) of the total EU Structural and Cohesion Funds allocation to transport between 2007 and 2013 was intended for rail infrastructure.

(2014) consider a range of cities from many countries and have studied this phenomenon for the larger European area. Yet, due to limited data availability, the most extended dataset of these studies (Oueslati et al., 2014) covered 282 European cities for a period of 16 years (1990-2006).

The main goal of this paper is to estimate the *causal joint* effect of highways and railways on the suburbanization of European cities using a new, currently unpublished census population dataset that covers almost all municipalities in Europe during the period 1961-2011. We have matched this dataset with Eurostat's *Large Urban Zone* (hereafter LUZ) and *Core City*<sup>3</sup> (CC) definition and we have constructed a unique urban population dataset which covers an extensive sample of the European cities for the aforementioned period. For the purpose of this analysis, we use 579 LUZ from 29 European countries, each of them including both core city and suburbs. These cities comprise roughly 59% of the selected countries' population in 2011. We have used GIS software to calculate the number of highway and railway rays, length and nodes (ramps and stations) that connect the central cities with their suburbs for the modern transport network, for a number of different types of historical transport infrastructure, for the geographical variables and for the historical variables at a very detailed spatial level. By creating most of the variables that we use in this analysis, we were able to overcome one of the main problems that impedes such analyses in the European level; namely, the availability of urban data collected for all the countries with a harmonised methodology.

In order to address the endogeneity issues, we have adopted the common two-stage instrumental variables (IV) approach in a panel data framework. We take advantage of the rich history of Europe, a part of which is reflected in the number of different types of transport infrastructure since the Roman roads (2,000 years ago)<sup>4</sup>. In particular, we found that the main post routes in 1810 and the railways in 1870 may explain the topology of the modern transport network<sup>5</sup>, while being exogenous to modern suburbanization.

One first novelty of this paper is that we have effectively estimated the *joint* suburbanization effect of highways and railways. Our results suggest that both highway and railway rays have contributed to the suburbanization of European cities in the period 1961-2011. However, the estimated effect for highways and for railways differs substantially in its magnitude. Our main estimates indicate that an additional highway ray displaced approximately 6% of the European central city population while the same estimate for the stock of radial railways was weaker and only about 2% between 1961 and 2011.

These findings are in line with previous studies that have estimated the effect of highways<sup>6</sup> on decentralization for US (Baum-Snow, 2007a), China (Baum-Snow et al., 2014) and Spain (Garcia-López et al., 2015). However, we find that the individual transport mode suburbanization effect

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<sup>3</sup>Or *central cities* as we mostly refer to them in this paper.

<sup>4</sup>The historical transport variables that have actually been tested in this study as potential valid instruments are the Roman roads, the main trade routes in the Holy Roman Empire and nearby countries in 1500, the main and secondary post routes in 1810 and the railways in 1870. Most of these variables have never been used before in such studies.

<sup>5</sup>The title of this paper is inspired by the fact that the modern highway system that facilitates the "express" (fast) delivery of goods and people to and from the suburbs has followed the main post route network that facilitated the faster delivery of mail in 1810.

<sup>6</sup>In Baum-Snow et al. (2014), railroads and ring roads are also included.

is overestimated to a certain extent when each transport mode is considered separately. Another interesting finding of this paper is that the effect of highway on suburbanization cannot be solely attributed to highway penetration via the number of rays. Suburban connectivity and suburban accessibility, as measured by the length of the suburban highway network and the number of suburban highway ramps, seem to have effected suburbanization too.

## 2 Theoretical framework and estimation strategy.

### 2.1 Theoretical framework.

Transport costs form the backbone of most urban and regional economics theories that try to explain the spatial distribution of economic activity. The classical monocentric land use theory developed by Alonso (1964), Mills (1967) and Muth (1969) predicts that declining transport costs push some people away from the center, lowering central city population density. Wheaton (1974) shows that a larger metropolitan population also expands the metropolitan boundary and raises densities everywhere in the city without changing the rent and density gradients in an "open" city system. Combining both population growth and transportation effects, rent and density gradients flatten, while rent and density increase in the suburbs.

Based on this extension of the basic monocentric model and the model of radial commuting highways proposed by Baum-Snow (2007b), we estimate the effect of highway and railway rays on central city population change. While the related literature has mainly focused on long-difference specifications to estimate the suburbanization effect, we use a panel specification which allows us to control for unobservable city characteristics and for a time trend. In addition, using the panel data approach, we can not only estimate the individual effects (equations 1 and 2), but also the joint effect that highways and railways exerted on the suburbanization of European cities (equation 3).

$$\ln(Pop_{it}^{CC}) = \alpha_0 + \alpha_1 highway\ rays_{it} + \alpha_2 Pop_{it}^{LUZ} + \eta^{country} + \eta^{decade} + \epsilon_{it} \quad (1)$$

$$\ln(pop_{i,t}^{CC}) = \beta_1 railway\ rays_{i,t} + \beta_2 \ln(pop_{i,t-1}^{LUZ}) + \vartheta^{LUZ} + \vartheta^{decade} + \epsilon_{i,t} \quad (2)$$

$$\ln(pop_{i,t}^{CC}) = \gamma_1 highway\ rays_{i,t} + \gamma_2 railway\ rays_{i,t} + \gamma_3 \ln(pop_{i,t-1}^{LUZ}) + \iota^{LUZ} + \iota^{decade} + \epsilon_{i,t} \quad (3)$$

where  $\ln(Pop_{it}^{CC})$  is the logarithm of population living in the CC of the city  $i$  in year  $t$ .  $highway\ rays_{it}$  is the number of highway rays penetrating the CC of city  $i$  and  $railway\ rays_{i,t}$  is the same measure for radial railways. We use LUZ and decade fixed effects in order to control for observable and unobservable characteristics that are city-specific (invariant between decades) and we control for general decade trends (invariant among cities).

## 2.2 Endogeneity issues.

One major concern regarding the estimation of equations (1), (2) and (3) is the potential endogeneity issue which may arise as a result of simultaneous causality bias between the transport infrastructure variables and the population change in the CC. As it has been argued in the literature (Baum-Snow, 2007a; Garcia-López et al., 2015), not only highways may affect the central city population change, but also the prospective of a city to grow or decline may affect the policy-making decisions regarding the allocation of the new lines of transport infrastructure in the cities.

Another endogeneity issue could emerge because unobservable for the researcher factors, such as the urban economic growth or income, may cause omitted variable bias in an OLS specification. It is obvious that the economic growth of a city may affect both the CC population change and the allocation of the transport infrastructure. In European cities, the bias introduced by both these concerns could either be positive or negative. On the one hand, more transport infrastructure investments were allocated to the more thriving urban areas, in terms of population or income. On the other hand, EU regional and cohesion policies (and even some national policies), were mainly focused to the more lagging regions and cities, in order to promote their growth potential and their convergence with the rest of the EU.

In order to obtain an unbiased estimate of the effect of transport infrastructure improvements on CC population change, we use two-stage least squares (TSLS) regressions using instrumental variables (IV). We argue that the exogenous variation provided by the historical transport infrastructure measures, which we use as instruments, allows us to overcome endogeneity issues. However, using panel data IV requires an instrument which varies over time.

We follow the way that Baum-Snow (2007a) constructed the smoothed rays in the plan instrument in order to construct our own "smoothed" instruments. Smoothed post routes are calculated by multiplying the number of post route rays in the 1810 by the fraction of the highway mileage in each LUZ completed at each point in time<sup>7</sup>. Hence, the rays' instruments become continuous and vary over time. An illustrative example, the post route instrument could be thought as the segment of the 1810 post route rays that would have been completed in every decade had the post route network followed the rate of evolution of the modern highway network (length). It should be mentioned that the fraction of the constructed network (smoothing factor) is a weight which gets taken in the interval [0,1]. Therefore, the number of smoothed post route rays will never be higher than the actual number of post route rays and it will always be zero for LUZ that have no post route rays in 1810. Using the same approach, we have constructed the smoothed radial railways in 1870 and we have applied the same methodology for the post route and rail in 1870 length variables. Equation (4) presents the first-stage specification for the number of rays.

$$\widehat{Transport\ rays}_{it} = \delta_0 + \delta_1 Smoothed\ historical\ rays_{it} + \delta_2 Pop_{it}^{LUZ} + \kappa^{country} + \kappa^{decade} + \epsilon_{it} \quad (4)$$

Finally, equation (5) presents the first-stage estimation of a long-difference specification. We

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<sup>7</sup>The same process is followed for calculating the smoothed radial railways in 1870

choose to show this specification because of the importance of geographical and historical variables as controls for the first-stage estimation.

$$\widehat{Transport\ rays}_i = \zeta_0 + \zeta_1 Historical\ rays_i + \sum \zeta_2 Controls_i^{CC+LUZ} + \lambda^{country} + v_i \quad (5)$$

In order to capture geography, we use the mean elevation and the range of altitude, the mean ruggedness for each LUZ, as well as the logarithm of the distance from each LUZ centroid to the nearest coast. In order to control for the role of history, we use the logarithm of city population in 1850 and dummy variables for the historical major cities (in 1000 and 1450), for cities with universities between the 12<sup>th</sup> and 15<sup>th</sup> century, for cities with Roman settlements and for cities with bishoprics (in 600, 1000 and 1450). We also include a variable for the existence of a historical city centre or another landmark denominated by UNESCO and a dummy for cities with medieval monasteries. These two variables may also be regarded as historical urban amenities variables.

The main reason why the inclusion of geographical and historical control variables is crucial in these specifications is to test the instrument exclusion restriction. In addition, they could create omitted variable bias in the first-stage estimation. It is obvious that geographical landscape is a variable that is correlated with the construction of both modern and historical transport infrastructure. Moreover, "historical urban amenities are determined mainly by past economic decisions regarding investment in urban infrastructure" (Brueckner et al., 1999). It could be argued that some of these historical variables may have affected the allocation of modern transport infrastructure too. For instance, major cities in the 19th century or cities with bishoprics may have more historical transport infrastructure endowments because of their economic or political influence at that time. However, the same historical variables may have influenced the allocation of modern transport infrastructure to these cities because of the value embedded in cultural heritage in modern times.

### 3 Data.

The urban population dataset that is used in this paper was constructed using census population data collected every 10 years at the municipality level for the period 1961-2011 in 34 European countries<sup>8</sup>. In our analysis, we use 29 countries that data were complete and that Eurostat includes in the Urban Audit. The countries included in our dataset are the member-states of EU28<sup>9</sup> except for Slovenia and Lithuania that data were not available, plus the non-EU countries, Switzerland, Norway and Iceland. This is the first time that this new integrated census population dataset is used in an academic paper, based on our knowledge.

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<sup>8</sup>The municipality population data series were provided by the DG Regio of the European Commission.

<sup>9</sup>Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and United Kingdom.

The units of our analysis are the Core Cities (CC) and the Large Urban Zones (LUZ) as Eurostat defines them in the Urban Audit of 2008. Eurostat defines LUZ not only based on administrative and statistical unit borders but also based on commuting criteria, defining a functional urban area based on a perfectly harmonised methodology across Europe<sup>10</sup>. This definition comprises all the settlements that interact economically with the core (Arribas-Bel et al., 2011). This is why Eurostat's LUZ were chosen as the most appropriate spatial unit for the analysis of suburbanization in Europe. Urban Audit uses the concept of a Core City as a legal, administrative entity and defines these entities by their political/administrative boundaries. However, in spite of being one of the most solid and comprehensive statistical datasets available at the city level in Europe, Urban Audit suffers from many missing values, which makes the use of most of its variables almost infeasible.

This is why we use only the definition of the LUZ and the Core City areas<sup>11</sup> while we used the municipality level census population data in order to construct our unique coverage population dataset for European cities for the period 1961-2011. This was a complicated task which involved retrieving information for the numerous municipality mergers from the national statistical offices. Our final dataset comprises 579 LUZ with both core cities and suburbs for the period 1961-2011.

The transport infrastructure measures that are used in this paper were calculated using GIS maps of the road system and the railroad network in Europe<sup>12</sup>. These are digital vector maps with polylines and points of different types. From these maps, we have calculated the number of highway and railway rays following Baum-Snow (2007a) definition, as limited access highways connecting the central city to a significant part of the suburbs<sup>13</sup>. In order to construct our panel highway and railway network, we merged the RRG 2011 operational networks with other highway and railway GIS maps for each decade in the period 2011-1961. Finally, the RRG GIS Database provides information for the highway ramps and for the train stations.

To compute our potential historical instruments, we worked with two digital vector maps. For the 1810 post routes and for the 1870 railroads, we created our own GIS maps using the digitized files from the David Rumsey Historical Map Collection<sup>14</sup> and the map from the Historical GIS for European Integration Studies<sup>15</sup>, respectively. To calculate the number of these historical transport infrastructure rays, we have adopted the same definition that we use for the highways.

Other variables that are included in this analysis are historical variables. The main historical variables that we use are dummy variables for the major cities in 1000 and 1450 and the logarithm of 1850 population (Bairoch et al., 1988)<sup>16</sup>. In addition, we have created dummy variables for the

<sup>10</sup>Eurostat's LUZ approximate the *Functional Urban Area (FUA)* that OECD defines. The OECD and the European Commission developed a new harmonised definition of a city and its commuting zone in 2011. This new OECD-EC definition identified more than 800 cities with an urban centre of at least 50,000 inhabitants in the EU, Switzerland, Croatia, Iceland and Norway.

<sup>11</sup>For London and Paris, which are by far the biggest cities in our sample and that the limits of their Core City definition comprise only an extremely small part of their LUZs (0.04% and 0.8% respectively), we use Eurostat's *Kernel* definition since in these cases the CC area is extremely small with respect to the LUZ area and does not reflect the actual CBD.

<sup>12</sup>These datasets are part of the Büro für Raumforschung, Raumplanung und Geoinformation (RRG) GIS Database.

<sup>13</sup>Baum-Snow (2007a) uses CBD instead of the Core City.

<sup>14</sup>see <http://www.davidrumsey.com>.

<sup>15</sup>HGISE, see <http://www.europa.udl.cat/hgise>.

<sup>16</sup>The European cities which are included in this dataset are those that have had, at some time between 800 and 1800,



cities with universities between the 12<sup>th</sup> and 15<sup>th</sup> century, for cities with Roman settlements and for cities with bishoprics (in 600, 1000 and 1450). These latter variables could be regarded as proxies for past political influence. We also include a dummy variable for cities with medieval monasteries and a variable for the existence of an historical city centre or another landmark denominated by UNESCO, as historical urban amenities. This last variable is the weighted sum of a dummy variable for the existence of an historical city centre (weight=1) and another one for the existence of another landmark denominated by UNESCO (weight=0.5). Therefore the range of this variable is between 0 and 1.5.

Apart from these variables, we use additional control variables in order to avoid omitted variable bias in both stages of the long-difference estimation. Most of these variables were also created using GIS data. We use geographical control variables, namely the mean elevation, the range of altitude and the mean surface ruggedness of each CC and each LUZ<sup>17</sup>. Another important geographical variable is the distance of each LUZ centroid to the closest coastline.

### 3.1 Suburbanization in Europe.

In this section, we present some descriptive statistics of the population in the central cities and in the suburbs of the LUZ areas of our sample, which illustrate the degree of relative suburbanization in Europe. We define the *relative urbanization/suburbanization*<sup>18</sup> as the difference between the population growth in the CC and the population growth in the suburbs<sup>19</sup>. As it can be observed in the last row of the last column of table 1, European cities experienced suburbanization on average in the period 1961-2011. In addition, the degree of suburbanization does not vary substantially in time but it is rather relative stable during the whole period of study. This observation gives grounds for considering the whole period 1961-2011.

Table 1: Average population growth and (sub)urbanization

	1961-1971	1971-1981	1981-1991	1991-2001	2001-2011	1961-2011
Population Growth (LUZ)	12.29%	6.69%	3.66%	3.07%	5.29%	34.77%
(i) CC Population Growth	10.83%	4.23%	1.72%	0.13%	4.22%	22.62%
(ii) Suburban Population Growth	14.08%	7.49%	7.95%	6.25%	6.38%	49.61%
<b>Relative (Sub)urbanization [(i) - (ii)]</b>	<b>-3.26%</b>	<b>-3.26%</b>	<b>-6.22%</b>	<b>-6.11%</b>	<b>-2.16%</b>	<b>-26.99%</b>

Notwithstanding table 1 indicates that suburbanization is a process that on aggregate dominated in Europe, only 299 out of 579 urban centres (roughly 52%) that we use in our analysis actually experienced suburbanization. This seemingly contradicting evidence can be partly explained in table 2.

5,000 or more inhabitants.

<sup>17</sup>The GIS raster maps were downloaded by the Digital Elevation Model over Europe; see <http://www.eea.europa.eu/data-and-maps/data/eu-dem>.

<sup>18</sup>Urbanization/suburbanization hereafter.

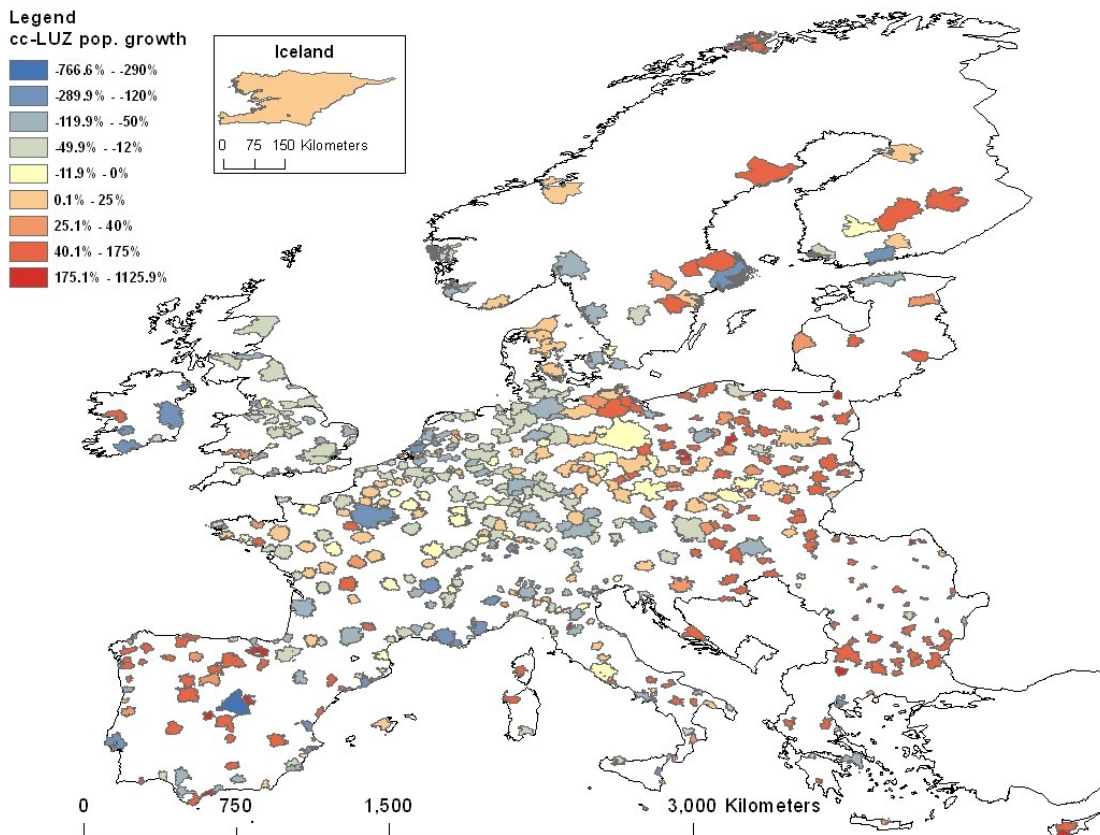
<sup>19</sup>We have relative urbanization when this difference is positive and relative suburbanization when this measure is negative.

There are two interesting observations that can be drawn by this table. The last column of this table shows that the overall suburbanization pattern that we highlighted in table 1 was mainly driven by the relative population change in the biggest cities of Europe (4<sup>th</sup> quartile). On the other hand, small and medium-small cities (1<sup>st</sup> and 2<sup>nd</sup> quartile) experienced quite intense urbanization during the first few decades but they have been suburbanizing for the last 20 years. also urbanised on average. On the other hand, medium-big (3<sup>rd</sup> quartile) cities experienced a mild suburbanization process and the most intense suburbanization occurred in big cities (4<sup>th</sup> quartile)<sup>20</sup>.

Table 2: Quartile city size (sub)urbanization by decade

City size quartiles (1961 LUZ residents)	1961-1971	1971-1981	1981-1991	1991-2001	2001-2011	1961-2011
1st (23,892 - 111,673)	27.84%	18.30%	7.88%	-5.00%	-5.47%	<b>62.14%</b>
2nd (111,674 - 178,017)	15.99%	6.89%	2.77%	-5.36%	-5.15%	<b>17.69%</b>
3rd (178,018 - 343,067)	7.01%	4.51%	-3.49%	-6.33%	-3.71%	<b>-3.35%</b>
4th (343,067 - 10,618,868)	-10.36%	-11.58%	-6.69%	-6.45%	-1.19%	<b>-44.36%</b>

Figure 1: Average relative (sub)urbanization in European cities (1961-2011).



Finally, another useful descriptive measure of the pattern of suburbanization in Europe can be obtained from map 1. Cities in East-European and Southern countries experienced significant

<sup>20</sup>This evidence seems to be in line with the sequential phases of urban development, namely, urbanization, suburbanization and desurbanization (van den Berg et al., 1982).

urbanization during the time that the cities of Western Europe decentralised<sup>21</sup>. This heterogeneous pattern of urbanization/suburbanization among cities of different sizes and among cities from different geographical locations motivated our heterogeneous estimations that we are currently working on.

### *3.2 The evolution of transport infrastructure in Europe.*

In this section, we describe the evolution of the modern transport network in Europe. The starting point of this evolution approximately coincides with the creation of the historical transport infrastructure network that we use to instrument the modern infrastructure variables. By describing this evolution, we provide arguments supporting our instruments' validity intuitively. The instrument relevance is tested empirically in section 4.1 where the first-stage estimations are presented. We start by discussing the highway network and then we move to the railroads' discussion.

#### *3.2.1 "Post-modern" highways.*

As it has been documented by Elias (1981, 1982), there are very few maps before 1650 showing roads in Europe. This can be explained by the high cost of travel during this early age, both because of the road quality and in terms of the opportunity cost of travel. Road maps became more common only about a hundred years later. In the beginning of the 17<sup>th</sup> century, governments realized that an improved road system could foster economic prosperity, better governance and that it could facilitate the creation of a reliable postal system. Post road systems were developed throughout Europe during the 17<sup>th</sup> and 18<sup>th</sup> centuries.

While roads remained relatively primitive until the middle of the 18<sup>th</sup> century, in the last quarter of the 18<sup>th</sup> century, the great improvement of roads, including hard surfaces and the development of much improved carriages, allowed for the use of wheeled coaches and wagons, which led to the development of coach service between towns. These coaches were primarily provided by the public mail service which was designed to carry letters, packages and people. Indeed, until the 19<sup>th</sup> century, most passenger coach travel was monopolized by postal carriers. These improvements resulted in a significant increase in road traffic, which resulted in the so-called "mail coach era", which lasted until the middle of the 19<sup>th</sup> century when railroads became the primary mode of transportation (Elias, 1981, 1982).

Very few 19<sup>th</sup> century post routes have been preserved in Europe. However, due to their increased popularity and the rough landscape of Europe, which restricts the construction of highways in a few "tracks", modern highways have followed the post routes' path. These two facts provide evidence that both the assumptions of instrument exogeneity and instrument relevance can be claimed very convincingly. Therefore, we argue that the main post routes in 1810 is a valid instrument that provides exogenous variation for the identification of the effect of highways on suburbanization.

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<sup>21</sup>van den Berg et al. (1982) related this pattern with the sequential phases of urban development, identifying the area that experienced suburbanization as the industrial cities founded during the Industrial Revolution.

Figure 2: Evolution of highways (1961-2011)

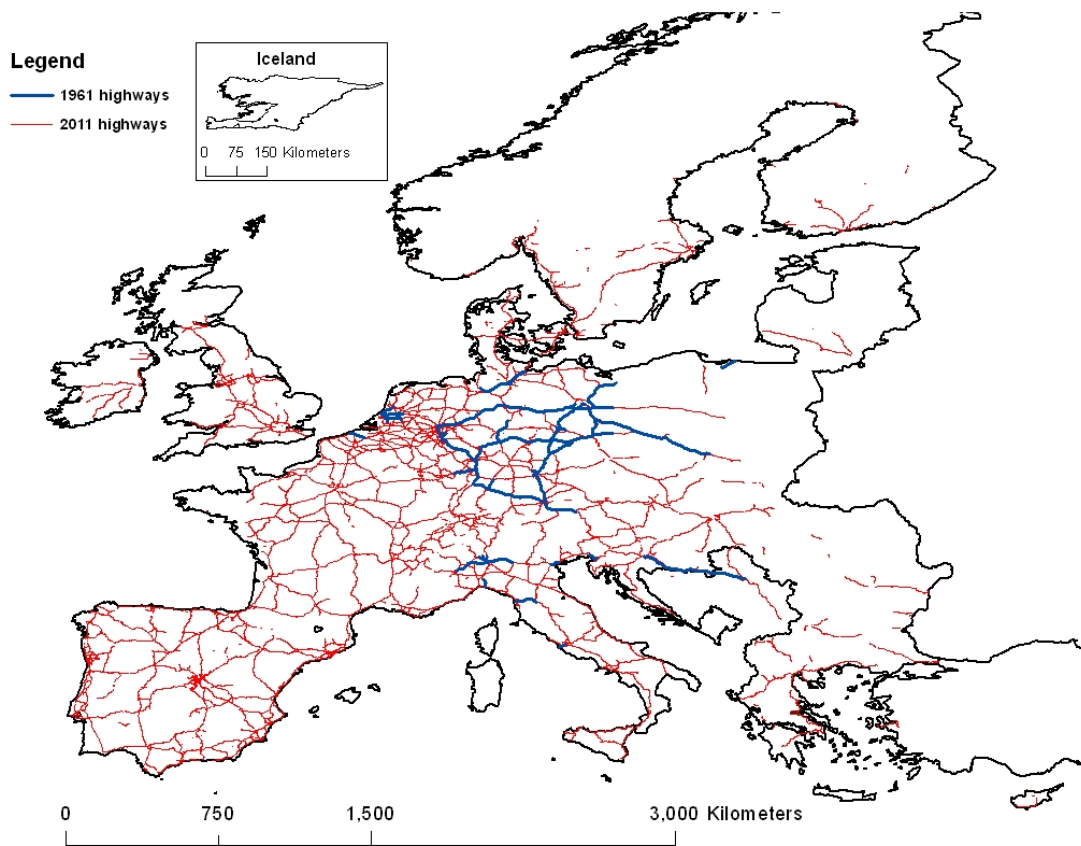


Figure 2 depicts the evolution of the highway network in Europe between 1961 and 2011. In 1961, there were only few highways, concentrated in a handful of countries<sup>22</sup>. However, by 2011, the highway network had extended almost over the whole European continent. The fact that in 1961 there was hardly any highway network in Europe allows us to use this year as the starting point of the highway network evolution.

### 3.2.2 Railroads network evolution.

The rail network development in Europe can be divided in four stages. The initial expansion of the network (1840-1860), its general expansion (1860-1910), its stabilisation (1910-1960) and then its reduction (1960-2010) (Martí-Henneberg, 2013). Until 1860, the existing railway network in Europe was very sparse. Only in UK it was relatively more dense. However, by 1870 already, railroads had spread out significantly across the whole continent. The importance of the railway network in Europe already by this age highlights its importance.

<sup>22</sup>In Germany, the Netherlands, some in North Italy and very few in Belgium, Croatia and Poland.

Figure 3a: The railway network in 1870.

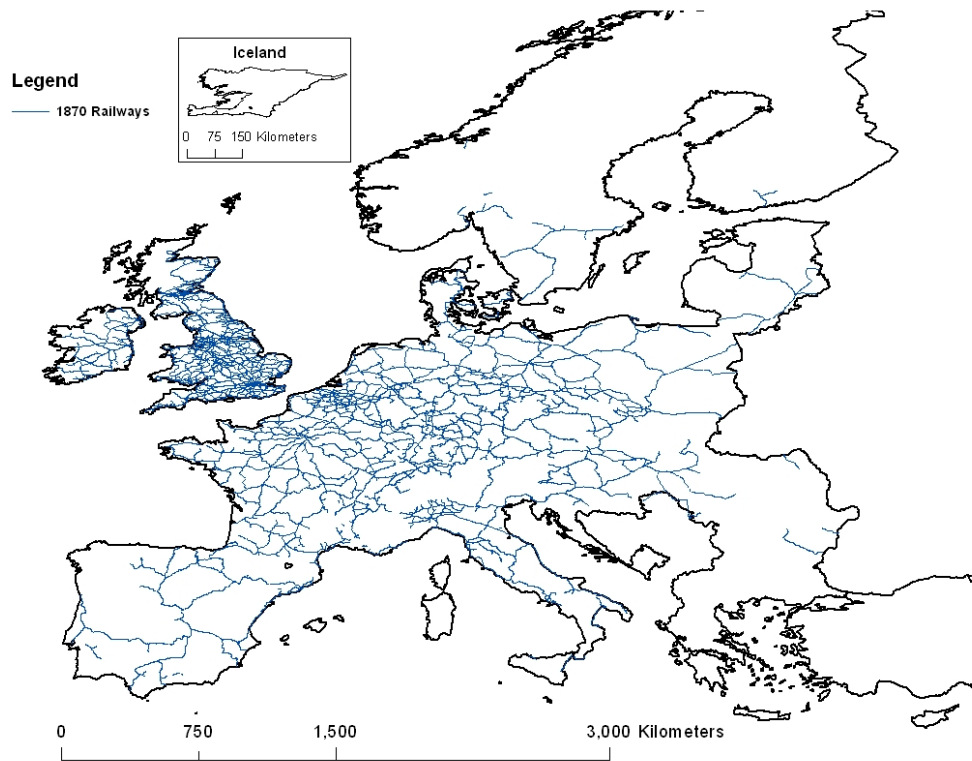
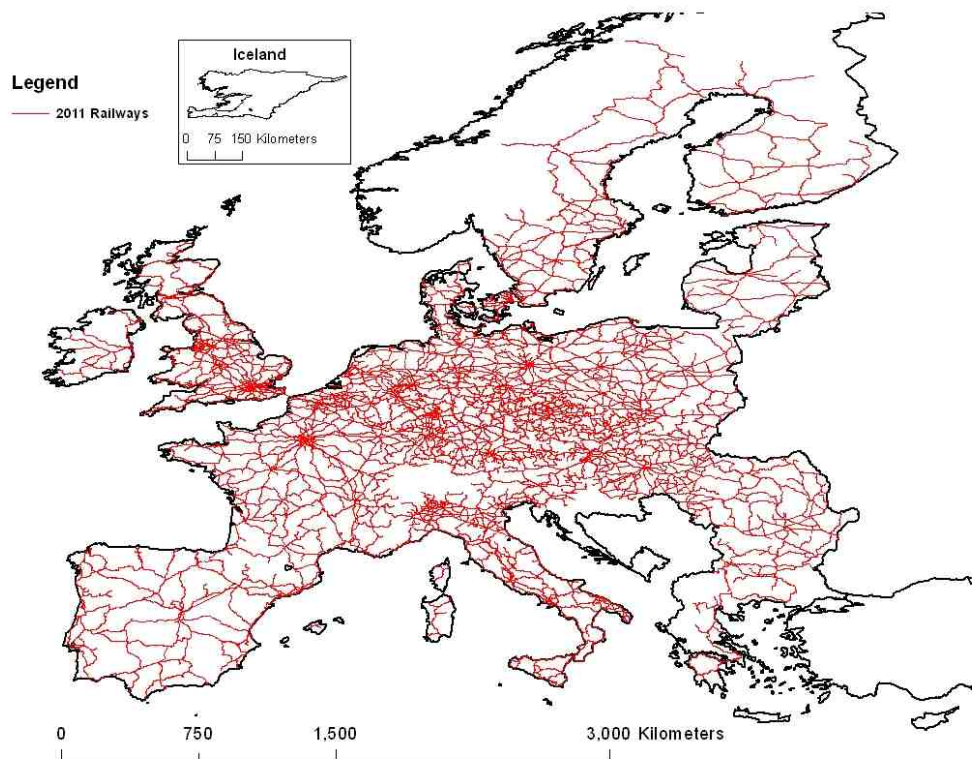


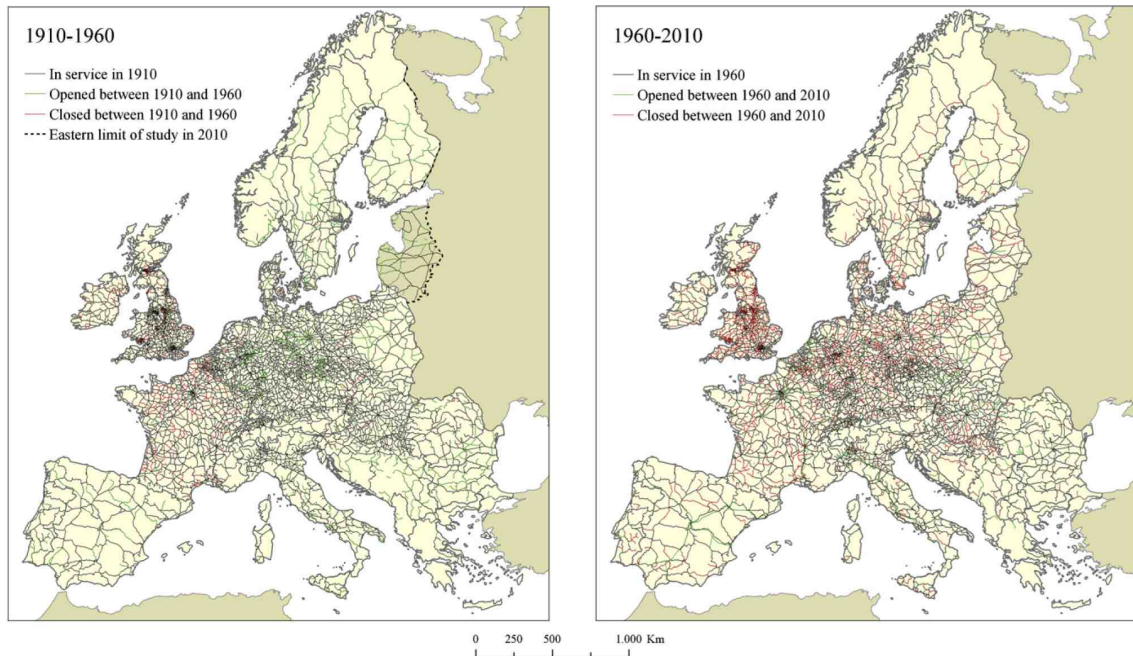
Figure 3b: The railway network in 2011.





As it can be shown by maps 3a and 3b, by 2011, the rail network had expanded almost everywhere in the European territory. However, in the period 1910-2010, numerous lines closed while many new lines were created as it can be seen in map 4. These 20<sup>th</sup> century changes in the rail network were mainly localised in the Western Europe, where the first railways in Europe were constructed. In some cases, these changes were driven by the underlying political factors<sup>23</sup>. The large number of lines closing and new lines opening suggests that the rail network changed radically between 1870 and 2010. These changes provide evidence that the existing railway network in 1870 could not have directly affected the population change in European CC between 1961 and 2011. At the same time, as maps 3a and 3b reveal and as the first-stage estimations (section 4.1) indicate, the railway rays in 1870 are very good predictors of the modern radial railways in 2011. Therefore, we consider that the instrument validity assumption can be plausibly claimed for the case of the radial railway too.

Figure 4: Evolution of the railway network in Europe (1910-2010).



Source: Martí-Henneberg (2013)

## 4 Results

### 4.1 First-stage results.

In section 3.2, we argued that the construction of modern transport infrastructure in Europe has followed the patterns of the historical transport routes in Europe. In addition, we argued that

<sup>23</sup>e.g. the Federal Republic of Germany rationalized its railway network after the large-scale expansion during the period corresponding to the Third Reich (Mitchell, 2006), while the Democratic Republic of Germany decided to maintain its public sector infrastructure.

historical transport infrastructure could not have possibly affected the population change in European core cities during the second half of the 20<sup>th</sup> and the beginning of the 21<sup>st</sup> century. In this section, we present the first-stage long-difference and panel estimates, which show that the historical transport infrastructure variables that we use as instruments can explain the expansion of the modern transport network. From all the historical transport infrastructure variables that we tried, we found that the main post routes in 1810 can explain the allocation of modern highways and the railway network in 1870 can be used to explain the allocation of modern railways.

In columns [1] and [2] of table 3, we present the results of the first-stage for the long-difference specification of equation (5) in section 2.2, which uses the number of highway rays in 2011 and the number of radial railways in 2011, as the main variables of interest, respectively. These specifications include control variables for both modern and historical city characteristics, as well as for geographical features. As we discussed in section 2.2 the use of historical and geographical variables is considered very important in order to avoid potential omitted variable bias and to make sure the instrument exclusion restriction holds.

The inclusion of historically major cities in 1000 and 1450 and the logarithm of 1850 population can also be used as a proxy for economic development in the previous centuries. As Tabellini (2010) suggests, in the past centuries, cities were the center of commerce whereas the industrial revolution further concentrated economic activities around major urban areas. For this reason, several studies have relied on city size as a measure of past economic development (De Long and Shleifer, 1993; Acemoglu et al., 2005). For the same econometric reasons, we also included dummy variables for the cities with universities between the 12<sup>th</sup> and 15<sup>th</sup> century, for cities with Roman settlements and for cities with bishoprics (in 600, 1000 and 1450). These variables could be regarded as proxies for political influence during the past centuries. We have also included a dummy variable for cities with medieval monasteries and a variable for the existence of an historical city centre or another landmark denominated by UNESCO, as historical urban amenity variables.

In addition, the coefficients of columns [1] and [2] in table 3 were estimated controlling for a series of geographical characteristics that may have affected the location of both modern and historical transport infrastructure. As Ramcharan (2009) argues, "countries with rougher surfaces have less dense surface transport networks". In particular, he reports a 1% increase in roughness is associated with about a 1% decline in the number of kilometres of roadway within a country. This negative relationship between roughness and transportation infrastructure appears to be consistent with the road construction literature, which suggests an exponential impact of terrain grade variation on the cost of building and maintaining roadways and rail lines, as well as on the time and energy required to move goods within a country and to maintain transport networks<sup>24</sup>.

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<sup>24</sup>See for example Aw (1981), Highway Research Board (1962) and Paterson (1987).

Table 3: Relation between historical and modern transport infrastructure.

Long-difference			Panel						
Dependent variable:	[1] highw. rays 2011	[2] radial rail 2011	Dependent variable:	[3] highw. rays	[4] radial rail	[5] ln(sub. highw. km+1)	[6] ln(sub. rail km+1)	[7] ln(sub. highw. ramps+1)	[8] ln(sub. rail sta- tions+1)
1810 post routes (rays)	0.105 <sup>b</sup> (0.0395)		Smoothed post routes (rays)	0.480 <sup>a</sup> (0.0296)					
1870 radial railways		0.552 <sup>a</sup> (0.110)	Smoothed 1870 radial railways		0.496 <sup>a</sup> (0.0650)				
CC+LUZ area	Y	Y	ln(1810 post route km+1)			1.154 <sup>a</sup> (0.0312)		0.444 <sup>a</sup> (0.0170)	
Geography and history	Y	Y	ln(1870 rail suburban km+1)				1.100 <sup>a</sup> (0.0527)		0.704 <sup>a</sup> (0.0440)
1961 ln(LUZ pop.)	Y	Y	ln(LUZ pop.)	Y	Y	Y	Y	Y	Y
Country FE	Y	Y	LUZ FE	Y	Y	Y	Y	Y	Y
	Y	Y	Decade FE	Y	Y	Y	Y	Y	Y
Observations	579	579	Observations	3,474	3,474	3,474	3,474	3,474	3,474
R-squared	0.593	0.616	R-squared	0.567	0.579	0.794	0.645	0.535	0.670

Notes:  
Notes: Geography variables are the mean and range of elevation, an index of terrain ruggedness for each LUZ and the logarithm of the distance to the closest coast from the CC centroid. History is controlled by the inclusion of dummy variables for historical major cities (in 1000 and 1450) and for the logarithm of city population in 1850, for cities with universities between the 12<sup>th</sup> and 15<sup>th</sup> century, for cities with Roman settlements, for cities with bishoprics (in 600, 1000 and 1450), for cities with medieval monasteries and for cities with historical city centres or another landmark denominated by UNESCO. Standard errors clustered by country are in parentheses. <sup>a</sup>, <sup>b</sup>, and <sup>c</sup> indicates statistical significance at 1, 5, and 10 percent level, respectively.



Columns [3]-[8] show the first-stage results for all the alternative highway and railway variables that we use in table 4 in the following section 4.2. In columns [3] and [4], we show the first-stage results when we use our smoothed rays instruments for the highways and the railways. In columns [5] and [6] we instrument the logarithm of suburban highway or railway kilometres<sup>25</sup> with the logarithm of smoothed instruments' length. Finally, in columns [7] and [8], we use the same instruments as exogenous variation for the logarithm of the number of suburban ramps and suburban train stations. It is clear from table 3 that all the instruments are very relevant.

#### 4.2 Main panel results.

In section 4.1, we showed that both post routes in 1810 and railways in 1870 are good predictors of the modern transport infrastructure. In this section, using this exogenous variation, we will test the hypothesis that highway and railway rays have contributed to the suburbanization of European cities. In order to test this hypothesis, we will estimate the effect of highway rays and radial railways on central city (CC) population in the period 1961-2011 using some panel specifications following those of equations 1, 2 and 3 .

All the results presented in table 4 are the second stage estimations of the IV approach described earlier. We will not present the OLS results as the relevant literature has already acknowledged that OLS is biased in this context. Panel A of table 4 presents the rays' results for the highway and railway rays. The dependent variable is the logarithm of the CC population in each year/decade in the period 1961-2011. The first column presents the results for the highway rays alone. Likewise, column [2] presents the results for radial railways alone and column [3] presents the results when including both highway rays and radial railways. Similarly, columns [4]-[6] show the individual and joint effect of the logarithm of suburban highway or/and suburban length and columns [7]-[9] show the same specifications for the logarithms of suburban highway ramps and train stations. Finally, in specifications [10] and [11], we attempt to jointly estimate the effects of highway rays and radial railways, together with the suburban variables.

Column [1] and [2] indicate that both highway and railway rays are highly statistically significant and negative when considered separately. The highway penetration marginal effect on suburbanizations is almost double compared to the radial railways' coefficient. However, column [3] is much more instructive and interesting since it takes into account both types of transport infrastructure. Column [3] indicates that the highway rays' effect remains hardly unchanged while the radial railways' effect become notably weaker both in value and in statistical significance. This could be explained by the fact that highways and railways are alternative commuting choices that "co-exist". Therefore, when examined individually, railways might capture some of the suburbanization effect caused by highways. Effectively considering the two transport modes jointly is considered an important improvement of this paper.

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<sup>25</sup>Where before taking the logarithms, we have added one km to all observations to avoid missing values in cities with no highways.

Table 4: Main panel results.

Panel A				Panel B						Panel C	
Rays				Suburban length and nodes						All	
Dependent variable: $\Delta \ln(\text{CC pop.})$	Highw. [1]	Rail [2]	Joint [3]	Highw. [4]	Rail [5]	Joint [6]	Highw. [7]	Rail [8]	Joint [9]	Joint [10]	Joint [11]
Highway rays	-0.066 <sup>a</sup> (0.008)		-0.061 <sup>a</sup> (0.008)							-0.036 <sup>b</sup> (0.016)	-0.039 <sup>a</sup> (0.015)
Radial rail		-0.037 <sup>a</sup> (0.013)	-0.021 <sup>c</sup> (0.013)							-0.025 <sup>b</sup> (0.013)	-0.031 <sup>b</sup> (0.013)
ln(sub. highw. km+1)				-0.038 <sup>a</sup> (0.005)		-0.038 <sup>a</sup> (0.005)				-0.018 <sup>c</sup> (0.010)	
ln(sub. rail km+1)					-0.010 (0.009)	-0.010 (0.009)					
ln(sub. highw. ramps+1)							-0.010 <sup>a</sup> (0.012)		-0.010 <sup>a</sup> (0.012)		-0.043 <sup>c</sup> (0.023)
ln(sub. rail stations+1)								-0.016 (0.014)	-0.019 (0.015)		
LUZ population	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
LUZ FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Instruments:											
1810 post routes (rays)	Y	N	Y	N	N	N	N	N	N	Y	Y
1870 radial railways	N	Y	Y	N	N	N	N	N	N	Y	Y
ln(1810 post route km+1)	N	N	N	Y	N	Y	Y	N	Y	Y	Y
ln(1870 rail suburban km+1)	N	N	N	N	Y	Y	N	Y	Y	N	N
Observations	3,474	3,474	3,474	3,474	3,474	3,474	3,474	3,474	3,474	3,474	3,474
Number of luz n	579	579	579	579	579	579	579	579	579	579	579
First-Stage F-statistic	262.7	58.34	30.21	1368	436.7	218.0	683.2	255.8	344.6	27.44	22.71
Stock & Yogo (2005) 10% critical values	16.4	16.4	7	16.4	16.4	7	16.4	16.4	7	-	-

Notes: Standard errors clustered by LUZ are in parentheses. <sup>a</sup>, <sup>b</sup>, and <sup>c</sup> indicates statistical significance at 1, 5, and 10 percent level, respectively.

Specification [3] suggests that an additional highway ray built in the period 1961-2011 displaced 6.1% of the CC population while the same effect for an additional railway was estimated at 2.1%. Even if both highway and railway rays seem to have affected suburbanization in European cities, in columns [4]-[9], we use alternative suburban highway and railway measures to test whether the aforementioned effects were solely driven by the radial structure of the transport networks. Columns [4] and [5] include the logarithm of suburban and railway highway lengths, respectively, and column [6] includes the two variables jointly. Whereas suburban railway length seems not relevant, suburban highway length is highly statistically significant and negative. The suburban highway length coefficient indicates that a 10% in the suburban highway network caused a 0.4% decrease of the CC population.

Specifications [7]-[9] show the same results for the suburban highway ramps and railway stations. These results are in line with the previous results for suburban length. Railway stations seem to be irrelevant to suburbanization while a 10% increase of the number of highway ramps is associated to a 0.1% displacement of CC population.

Finally, in panel C, we attempt to estimate the joint effect of highway and railway rays together with the previously statistically significant, alternative highway measures. This estimation shows that all the coefficients of highway rays, radial railways and suburban highway length/nodes are jointly statistically significant. However, the highway coefficients should be interpreted with caution due to the high correlation between the highway rays and the suburban variables. Nonetheless, columns [10] and [11] indicate that the highways potentially caused suburbanization in European cities through more than one channel.

## 5 Work in progress

We are currently working in heterogeneous effects of highways and railways on suburbanization. As it has been mentioned in the literature, except for the differences in the nature and pattern of suburbanization and sprawl between Europe and US (Brueckner et al., 1999), there are also intra-European variations in these processes (Oueslati et al., 2014). Countries, regions and cities in Europe followed different socio-economic development paths, a fact which is reflected in their modern urban structure. In this paper, we employ this heterogeneity in order to identify different patterns of the estimated effect for different geographical regions, for regions of different economic performance and for different groups of cities based on their size and their coastal or inland location.

In particular, some preliminary results indicate that the highway effect on suburbanization is higher for the Eastern European regions and for the small cities, while it is not so significant for the cities of the Central-North Europe. For radial railways, we found that they affect the decentralization of population more in the Mediterranean area, in the smaller cities and in the inland cities. On the other hand, in the Central-North Europe, in big cities and in coastal cities there is virtually no effect of the railways on suburbanization. Finally, a very important finding is that the effect of highway penetration on suburbanization was significantly larger in the poorer regions which

received large amounts of EU regional funding for transport infrastructure improvements.

Another forthcoming part of this paper is the robustness analysis. For this reason, we will use a modified version of the algorithm used in Baum-Snow et al. (2014) as an alternative rays measure. In addition, we will use alternative CC definitions in order to address the endogeneity concerns regarding the definitions of CC and LUZ areas.

## References

- Acemoglu, D., Johnson, S., and Robinson, J. (2005). The rise of europe: Atlantic trade, institutional change, and economic growth. *American Economic Review*, 95(3):546–579.
- Acs, Z. (2006). *The growth of cities*. Edward Elgar Publishing.
- Alonso, W. (1964). *Location and land use: toward a general theory of land rent*. Harvard University Press.
- Arribas-Bel, D., Nijkamp, P., and Scholten, H. (2011). Multidimensional urban sprawl in europe: A self-organizing map approach. *Computers, Environment and Urban Systems*, 35(4):263–275.
- Aw, W. B. (1981). *Highway Construction Cost Model for Sector Planning in Developing Countries*. Massachusetts Institute of Technology, Department of Civil Engineering.
- Bairoch, P., Batou, J., and Chevre, P. (1988). *Population of European cities from 800-1860*. Geneva University, Centre of International Economic History, Geneva (CH).
- Batty, M., Besussi, E., and Chin, N. (2003). Traffic, urban growth and suburban sprawl. CASA working paper, Centre for Advanced Spatial Analysis (UCL): London, UK.
- Baum-Snow, N. (2007a). Did highways cause suburbanization? *The Quarterly Journal of Economics*, 122(2):775–805.
- Baum-Snow, N. (2007b). Suburbanization and transportation in the monocentric model. *Journal of Urban Economics*, (62):405–423.
- Baum-Snow, N., Brandt, L., Henderson, J., Turner, M., and Zhang, Q. (2014). Roads, railroads and decentralization of chinese cities. *Mimeo*.
- Becker, S. O., Egger, P. H., and von Ehrlich, M. (2012). Too much of a good thing? on the growth effects of the EU’s regional policy. *European Economic Review*, 56(4):648–668.
- Bertaud, A. (1999). Cracow in the twenty first century: Princes or merchants.
- Bertaud, A. (2004). The spatial structures of central and eastern european cities: more european than socialist?
- Brueckner, J. K. (2000). Urban sprawl: Diagnosis and remedies. *International Regional Science Review*, 23(2):160–171.
- Brueckner, J. K. (2001). Urban sprawl: Lessons from urban economics. *Brookings-wharton Papers on Urban Affairs - Brookings Wharton Paper Urban Aff*, 2001(1):65–97.
- Brueckner, J. K. and Largey, A. G. (2006). Social interaction and urban sprawl. CESifo Working Paper Series 1843, CESifo Group Munich.

- Brueckner, J. K., Thisse, J.-F., and Zenou, Y. (1999). Why is central paris rich and downtown detroit poor?: An amenity-based theory. *European Economic Review*, 43(1):91–107.
- Carruthers, J. I. and Ulfarsson, G. F. (2003). Urban sprawl and the cost of public services. *Environment and Planning B: Planning and Design*, 30(4):503–522.
- Couch, C., Petschel-Held, G., and Leontidou, L. (2008). *Urban Sprawl in Europe: Landscape, Land-Use Change and Policy*. John Wiley & Sons.
- De Long, J. and Shleifer, A. (1993). Princes and merchants: European city growth before the industrial revolution. *Journal of Law and Economics*, 36(3).
- Elias, W. (1981). *Road Maps for Europe's Early Post Routes 1630-1780*. The map collector.
- Elias, W. (1982). *Maps and Road Books of Europe's Mail Coach Era 1780-1850*. The map collector.
- European Commission (2010). Communication from the commission concerning the development of a single european railway area. Technical report.
- García-López, M.-A., Holl, A., and Viladecans-Marsal, E. (2015). Suburbanization and highways: when the romans, the bourbons and the first cars still shape spanish cities. *Journal of Urban Economics*, 85:52–67.
- Glaeser, E. L. and Kahn, M. E. (2004). Sprawl and urban growth. *Handbook of regional and urban economics*, Elsevier.
- Glaeser, E. L. and Kahn, M. E. (2010). The greenness of cities: Carbon dioxide emissions and urban development. *Journal of Urban Economics*, 67(3):404–418.
- Highway Research Board (1962). The AASHO road test. Special Report 61E Publication 944, National Research Council, Washington, DC: National Academy of Sciences.
- Krugman, P. (1991). Increasing returns and economic geography. *Journal of Political Economy*, 99(3):483–99.
- Martí-Henneberg, J. (2013). European integration and national models for railway networks (1840-2010). *Journal of Transport Geography*, 26:126–138.
- Mills, E. S. (1967). An aggregative model of resource allocation in a metropolitan area. *The American Economic Review*, 57(2):197–210.
- Mitchell, A. (2006). *The Great Train Race: Railways and the Franco-German Rivalry, 1815-1914*. Berghahn Books.
- Muth, R. F. (1969). *Cities and housing: the spatial pattern of urban residential land use*. University of Chicago Press, Chicago.

- Oueslati, W., Alvanides, S., and Garrod, G. (2014). Determinants of urban sprawl in european cities. Working Paper hal-00943319, HAL.
- Patacchini, E. and Zenou, Y. (2009). Urban sprawl in europe. *Brookings-Wharton Papers on Urban Affairs*, 2009(1):125–149.
- Paterson, W. D. O. (1987). Road deterioration and maintenance effects: Models for planning and management. Technical Report vol. III.
- Phelps, N. A. and Parsons, N. (2003). Edge urban geographies: notes from the margins of europe's capital cities. *Urban Studies*, 40(9):1725–1749.
- Pirotte, A. and Madre, J.-L. (2011). Determinants of urban sprawl in france: an analysis using a hierarchical bayes approach on panel data.(report). *Urban Studies*, 48(13):2865(22).
- Ramcharan, R. (2009). Why an economic core: Domestic transport costs. SSRN Scholarly Paper ID 1334726, Social Science Research Network, Rochester, NY.
- Redfearn, C. L. (2006). The emergence of centrality in a transition economy: Comparing land market dynamics measured under monocentric and semiparametric models. *Journal of Regional Science*, 46(5):825–846.
- Tabellini, G. (2010). Culture and institutions: Economic development in the regions of europe. *Journal of the European Economic Association*, 8(4):677–716.
- van den Berg, L., Sciences, E. C. C. f. R., and in Social, D. (1982). *Urban Europe: A study of growth and decline*. Pergamon Press.
- von Thunen, J. (1826). *The Isolated State*. Perthes, Hamburg.
- Wheaton, W. C. (1974). A comparative static analysis of urban spatial structure. *Journal of Economic Theory*, 9(2):223–237.