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

(Preliminary Incomplete Draft)

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ABSTRACT: The main goal of this paper is to provide evidence for the causal effect of transport 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 have constructed a unique population and transport infrastructure dataset covering 579 cities from 29 European countries during the period 1961-2011. We highlight the persistence of history in European cities, by using the main post routes in 1810 and the railroads in 1870 as instruments and we also control for historical population and urban amenities variables. Our preliminary results suggest that both highway and railway rays have a negative effect on central city population growth: a highway ray built between 1961 and 2011 caused a 9.5-10.5% decline on the average European central city population growth whereas this estimate for a railway ray was 2.5%.

Key words: suburbanization, cities, Europe, highways, railways, transport infrastructure
JEL classification: R4, O4

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1 Introduction

Urban theorists dating back from von Thunen (1826) to Krugman (1991) have argued that when transportation is expensive, activities will group together to save on travel costs. This is one of the main reasons why in the industrialized world, cities have become the nuclei of economic development (Acs, 2006). Nonetheless, transportation technologies and infrastructure also shape cities and dictate urban form (Glaeser and Kahn, 2004). Transportation improvements affect commuting and the transport costs that the principal city agents face in a city. This effect can be seen as a direct benefit resulting from the decline in the travel cost. Via this mechanism, urban economics theoretical models predict that transport infrastructure improvements facilitate the suburbanization process.

In this paper, we will test this hypothesis for Europe using a new 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*[1] (CC) definition and we construct a huge population dataset which covers most European cities for the aforementioned period. For the purpose of this analysis, we use 579 LUZ from 29 different European countries that include both core cities and suburbs. These cities comprise roughly 59% of the selected countries' population in 2011. We have used GIS software to calculate the number of rays that connect the central cities with their suburbs for the modern transport network, for a number of different types of historical transport infrastructure and for our geographical 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 impede such analyses in the European level; namely, the availability of data collected for all the countries with a harmonised methodology.

The main phenomenon that we are interested in is known as *relative suburbanization*[2] and together with the expansion of the urban area (*urban sprawl*), they may affect urban structure in many ways. Some consequences of the these processes that have been highlighted in the literature are the greater resource consumption and CO_2 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. On the other hand, there is another strand of literature (Brueckner, 2000, 2001) which argues that criticism of urban spatial expansion is only justified in the presence of market failures or other distortions. For instance, Brueckner and Largey (2006) tested empirically the hypothesis that low-density living reduces social interaction and they found not only that this positive relationship does not hold, but also that there is a negative relationship between density and social interaction. Although this literature is still inconclusive about the overall effect and the exact determinants of the suburbanization, transport infrastructure is widely acknowledged as one of the main factors affecting this process.

Suburbanization and urban sprawl are two interrelated processes, which are regarded as major issues in Europe. Even though Glaeser and Kahn (2004) suggest that "the primary social problem

[1] Or *central cities* as we mostly refer to them in this paper.

[2] When the population growth of the suburbs is higher than the population growth in the central city.

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 most academics in Europe have adopted a different point of view. This is reflected in the *Europe 2020* strategy goals, which focuses on; the reduction of CO_2 emissions and the increase in energy efficiency; fighting social exclusion; education and R&D. In spite of the fact that the latter two seem to be irrelevant for this argument, they expresses a main opposition against the way that EU has allocated its funding, which could be argued that favors "hard infrastructure" (e.g. highways) against "soft infrastructure" (e.g. human capital) investments.

Although urban sprawl and suburbanization have been extensively studied in the US (Brueckner, 2000, 2001; Glaeser and Kahn, 2004; Baum-Snow, 2007), 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. (2014) consider a range of cities from many countries and have attempted to study this phenomenon for Europe as a whole. However, these latter studies were not able to address this issue for more than 282 European cities and for a period longer than 1990-2006 (Oueslati et al., 2014).

The first goal of this paper is to estimate the casual effect of highways and rail lines on the suburbanization process in European cities. One fundamental endogeneity issue with this estimation may rise because the prospective of a city for growth or decline may affect the policy-making decisions regarding the allocation of the new lines of transport infrastructure to the cities. In order to address this endogeneity issue, we have adopted the common two-stage instrumental variables approach, taking advantage of the 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)[3]. In particular, we found that the main post routes in 1810 may explain the location of modern highways[4] and that railways in 1870 may explain the modern railway network.

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 networks 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 favors the poorest regions[5]. Moreover, European cities not only possess exceptional possibilities for economic development but also unique historical, cultural and architectural qualities and strong forces of social inclusion (Directorate General for Regional Policy,

[3]The potential historical transport instruments that we have actually tested in this study are the Roman roads, the main trade routes in the Holy Roman Empire and nearby countries in 1500, the main and the secondary post routes in 1810 and the railways in 1870. Most of these variables have never been used before in such studies.

[4]The title of this paper is inspired by the fact that the modern highway system that facilitates the "delivery" of goods and people to and from the suburbs can be explained by the main post route network that facilitated the delivery of mail in 1810.

[5]The main criterion for the allocation of resources from the European Regional and Cohesion Funds is equity rather than efficiency (Becker et al., 2012). In particular, it depends on the share of regional GDP per capita with respect to the European average.

2011). These tokens of the ”historical glory” of European cities, together with the variety of urban amenities and the popularity of public transport in Europe, make central cities in Europe relatively more attractive than other places (Brueckner et al., 1999). Finally, the heterogeneous pattern of urbanization/suburbanization that we can observe in the cities of Europe, together with all the aforementioned ”European peculiarities” differentiates this paper from previous empirical works that have studied the same effect in the context of US (Baum-Snow, 2007), China (Baum-Snow et al., 2013) and Spain (Garcia-López et al., 2013).

Although differences in the nature and pattern of suburbanization and spawl have been observed between Europe and US (Brueckner et al., 1999), there are also intra-European variations in these processes (Oueslati et al., 2014). A first extension of this paper is to employ this heterogeneity in order to allow the identification of different spatial patterns of the estimated effect. Europe is also characterised by a more polycentric and less concentrated urban structure compared to, for instance, US or China, especially in the 23 cities of more than 1 million inhabitants (Directorate General for Regional Policy, 2011). At a later stage, we will explore how the transport infrastructure network has affected the polycentricity of the major European cities. In this extension, we will also consider intra-metropolitan public transit, as captured by the metro network and by the bus and tram networks. Finally, since we built our database using municipality population data, we will take advantage of our raw data and of the precision of our GIS transport infrastructure data so as to estimate the effect of having a highway ramp within the municipality borders using a diff-in-diff research design. In the last section of this draft, we discuss all the upcoming extensions and the work in progress in more detail.

In this incomplete preliminary version, the analysis is limited to what we have described already. Up to this point, our results suggest that both highway and railway rays have negatively affected the population growth in the central cities of Europe in the period 1961-2011, controlling not only for the usual population and area variables, but also for the role of geography, history and urban amenities. We estimated that an additional highway ray built between 1961 and 2011 caused 9.5-10.5% decline on the average European central city population growth while the same estimate for the stock of radial railways was 2.5%. Even though these results are preliminary, they are very relevant and they yield important policy implications for Europe.

All this background highlights the importance of this paper and the implications for the European policies. The insight that may emerge from this analysis could be combined with studies that explore the optimal city size based on the trade-off between agglomeration economies and urban costs (Henderson, 1974; Fujita and Ogawa, 1982). By so doing, the transport policies could be reshaped in order to satisfy the European goals of the increased connectivity and accessibility in the European territory, the goals of Europe 2020 strategy and to promote European cities in an optimal way.

2 Theoretical framework and related literature

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 greater 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, we estimate the effect of highways on central city population change. We use 1961-2011 population data, 2011 highway rays, 2011 radial railway data and other control variables in order to estimate the following regressions:

$$\Delta ln(Pop_i^{CC}) = \alpha_0 + \alpha_1 hwy_i + \sum \alpha_2 Controls_i^{CC} + \sum \alpha_3 Controls_i^{LUZ} + \epsilon_i \quad (1)$$

$$\Delta ln(Pop_i^{CC}) = \beta_0 + \beta_1 rlw_i + \sum \beta_2 Controls_i^{CC} + \sum \beta_3 Controls_i^{LUZ} + \epsilon_i \quad (2)$$

where $\Delta ln(Pop_i^{CC})$ is the change in the logarithm of population living in central city i between 1961 and 2011. hwy_i is the number of highway rays computed following the definition of Baum-Snow (2007) and rlw_i are radial railways measured in the same way. $Controls_i^{CC}$ and $Controls_i^{LUZ}$ are core city and LUZ control variables respectively. The characteristics for which we control in our main estimations are the logarithm of the core city and the LUZ area, the change in the logarithm of LUZ population between 1961 and 2011, the logarithm of the 1961 population in the suburbs, geography, history and urban amenities. We capture geography by the mean elevation and the range of altitude, the mean ruggedness, as well as the logarithm of the distance of each LUZ centroid to the nearest coast. In order to control for history, we use the logarithm of city population in 1850. Urban amenities are reflected in the ratios of green area to the total area in the central city and the suburbs respectively, in the preservation of a cultural heritage denominated by UNESCO in a city centre and in the existence of a university before 1960 in a city. Finally, ϵ_i is the error term.

A number of recent papers have investigated the role of transport infrastructure on different aspects of the urban form. One seminal paper that stands out from this literature is the one of Baum-Snow (2007). The author estimates the causal effect of the interstate highway system in US and finds that one new highway passing through a central city reduces its population by about 18% between 1950 and 1990. In this paper, the planned portions of the interstate highway system are used as a source of exogenous variation in order to address the endogeneity issues. Garcia-López et al. (2013) have adopted a similar approach for the case of Spain. Their results show that each highway ray caused 8-9% decline in central city population between 1960 and 2010. Baum-Snow et al. (2013) have also tested this hypothesis in the context of a developing country, China. In this study, railways and ring roads were also included. The authors found that each radial highway displaces at least 5% of central city population to surrounding regions but no significant effect of radial railways on central city population change.

Baum-Snow (2010) has also extended the scope of the previous analysis to an intra-metropolitan perspective, investigating the effect of highway improvements on commuting patterns within and between central cities and suburbs. Garcia-López (2012) and Garcia-López et al. (2013) have also adopted an intra-metropolitan perspective for the case of Barcelona and Spain, respectively. The former verifies Baum-Snow (2007)'s findings and extends them by showing that the transit system also affects the location of population inside the central business district. The latter finds that their 8-9% estimated effect was much higher for suburban municipalities where ramps were located and for those located closer to a ramp.

While the aforementioned literature has studied the effects of transport infrastructure in the distribution of population within a city, another seminal paper by Duranton and Turner (2012) estimates the effect of interstate highways on the growth of US cities between 1983 and 2003. The authors found that a 10% increase in a city's initial stock of highways caused about 1.5% increase in its employment over this 20 year period. At a county level, Jiwattanakulpaisarn et al. (2009) had previously studied the effect of highway infrastructure investment on employment growth albeit Michaels (2008) has analysed the relationship between highways and workers' earnings. Duranton and Turner (2011) and Hsu and Zhang (2014) provide evidence for the effect of highway improvements on congestion in the cities of US and Japan, respectively. Finally, Donaldson (2014) analysed the incidence of Indian railroads in late 19th and early 20th century and found big effects on trade and welfare.

3 Data

The main 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 29 European countries[6]. The countries included are the member-states of EU28[7] 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 population dataset is used in an academic paper, based on our knowledge.

We are using the 2008 Eurostat's Urban Audit's definition of Large Urban Zones (hereafter *LUZ*) and Core Cities (*CC*) as the unit of our analysis. 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. 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. Urban audit uses the concept of a core city as a legal, administrative entity and defines these entities by their political boundaries. However, in spite of being one of the most solid and com-

[6]The municipality population series were provided by the European Commission DG Regio.

[7]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, United Kingdom.

prehensive 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 unfeasible (Arribas-Bel et al., 2011).

This is why we use only the definition of the LUZ and the core city areas[8] while we used 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 fo the numerous municipality mergers in Europe from the national statistical offices. Our dataset comprises 579 LUZ with both core cities and suburbs around Europe in the period 1961-2011.

The transport infrastructure variables were calculated using GIS maps of the 2011 and 1961 road system and the 2011 railroad network in Europe. These are vector digital maps with polylines of different types[9] and points[10]. From these maps, we have calculated the number of highway and railway rays following the definition of Baum-Snow (2007), i.e. limited access highways connecting the central city[11] to a significant part of the suburbs. To compute our potential historical instruments, we work with three vector digital GIS maps. For the 1810 European post routes and for the 1870 railroads, we create our own GIS maps using the digitized files from the David Rumsey Historical Map Collection[12] and the map from the Historical GIS for European Integration Studies[13], respectively. To calculate the number of these historical transport infrastructure rays, we adopt the highway ray definition.

From these historical transport variables, the main post routes in 1810 can explain the location of modern highways and the railway network in 1870 can explain the location of modern railways. The reason behind this relation is that the construction of modern transport infrastructure in Europe has followed the patterns of the historical transport routes in Europe. However, historical transport infrastructure could not have possibly affected the population change in European core cities during the second half of the 20th and the beginning of the 21st century as we argue later. Thus, we argue that both the assumptions of instrument relevance and instrument exogeneity are satisfied intuitively and empirically.

Apart from these main variables of interest, we use a series of control variables in order to isolate the effect that the transport infrastructure improvements exerted to the population change of the central cities in Europe and to avoid omitted variable bias. The historical population in 1850 is used as a control variable for the fact that past population may have determined the modern population change in a core city and in the LUZ as a whole. This measure can also be used as a proxy for economic development in the previous century. In the past centuries, cities were the center of commerce, whereas the industrial revolution further concentrated economic activities around major urban areas (Tabellini, 2010). For this reason, several studies have relied on city size

[8]For London and Paris, which are by far the biggest cities in our sample, we use Eurostat's *Kernel* definition since in these cases the core city area is extremely small with respect to the LUZ area and does not reflect the actual CBD.

[9]Motorways, dual-carriageway national and trunk roads and railroad segments.

[10]Ramps and stations.

[11]CBD in (Baum-Snow, 2007).

[12]see `http://www.davidrumseny.com`.

[13]HGISE, see `http://www.europa.udl.cat/hgise`.

as a measure of past economic development (De Long and Shleifer, 1993; Acemoglu et al., 2005).

Other such variables are geographical variables, namely the mean elevation, the range of altitude and the mean surface ruggedness of each central city and each LUZ[14]. Another important geographical variable is the distance of each city to the closest coastline. Furthermore, we use some variables that reflect urban amenities in the cities of Europe. Such variables are the ratio of urban green space area[15] in the core city and in the suburbs, the existence of a historical city centre or another landamark denominated by UNESCO in the World Heritage List[16] and the existence of a university in a city before 1960[17].

Finally, in the incomplete robustness analysis section, we use the mean temperature[18] at each LUZ as an instrument for the variable of the logarithm of LUZ population change. We have also included the logarithm of the number of municipalities in a LUZ [19] and the inverse of the logarithm of the distance of the LUZ centroid to the centroid of the closest LUZ area multiplied by the average population of the nearest LUZ area in the period 1961-2011.

3.1 Is suburbanization relevant in Europe?

In this section, we present some descriptive statistics of the population in the core cities and in the suburbs of the LUZ areas of our sample, which indicate the degree of relative suburbanization in Europe. We define the relative urbanization/suburbanization by the difference between the population growth in the central city minus the population growth in the suburbs[20]. As we can observe in the last raw of the last column of table 1, Europe experienced relative suburbanization on average in the whole period of study. In addition, the degree of relative suburbanization does not vary substantially in time but it is rather relative stable during the whole period of study.

Whereas table 1 indicates that relative suburbanization is the process that in the aggregate dominated in Europe, 299 of the 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 below. There are two interesting points in this table. The first one is that the overall relative suburbanization pattern that we highlighted in table 1 were mainly driven by the relative population change in the biggest cities of Europe (4$^{\text{th}}$ quartile). On the other hand, small cities (1$^{\text{st}}$ quartile) experienced quite extreme relative urbanization. Medium-small cities (2$^{\text{nd}}$ quartile) were also characterised by significant relative urbanization on average. In contrast, medium-big (3$^{\text{rd}}$ quar-

[14]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`.

[15]The Corine land use data that we use in order to compute the green area ratio are not available for Greece since the land use register is expected to be finished by 2020). For this reason we have to exclude the 9 cities of Greece in all the estimations that urban amenities are included.

[16]See `http://whc.unesco.org/en/list/`. This variable is the weighted sum of a dummy for the existence of an historical city centre (weight=1) and another dummy for the existence of another landmark denominated by UNESCO (weight=0.5). Therefore the range of this variable is between 0 and 1.5.

[17]The reason we only include universities before 1960 is to avoid simultaneous causality bias and given that almost 97% of the cities of the sample have at least one university currently, it makes no sense to include the current universities.

[18]See `http://www.worldclim.org/current`.

[19]To control for the number of Tiebout sorting options available.

[20]We have relative urbanization when this difference is positive and relative suburbanization when this measure is negative.

tile) cities experienced mild relative suburbanization and the most intense relative suburbanization occurred in big cities (4th quartile). This evidence seems to be in line with the subquential phases of urban development, namely, urbanization, suburbanization and desurbanization (van den Berg et al., 1982).

Table 1: Average Population Growth and Relative Suburbanization

	1961	1971	1981	1991	2001	2011
LUZ Population (thousands)	223,968	251,501	268,336	278,165	286,693	301,852
CC population (thousands)	123,112	136,441	142,212	144,662	144,852	150,960
Suburban population (thousands)	100,856	115,059	123,673	133,503	141,841	150,892
	1961-1971	1971-1981	1981-1991	1991-2001	2001-2011	1961-2011
LUZ Population Change (thousands)	27,533	16,835	9,830	8,528	15,159	77,885
CC Population Change (thousands)	13,329	5,770	2,451	190	6,108	27,848
Suburban Population Change (thousands)	14,204	8,614	9,830	8,338	9,051	50,037
Population Growth (LUZ)	12.29%	6.69%	3.66%	3.07%	5.29%	34.77%
CC Population Growth	10.83%	4.23%	1.72%	0.13%	4.22%	22.62%
Suburban Population Growth	14.08%	7.49%	7.95%	6.25%	6.38%	49.61%
Relative (Sub)urbanization	-3.26%	-3.26%	-6.22%	-6.11%	-2.16%	-26.99%

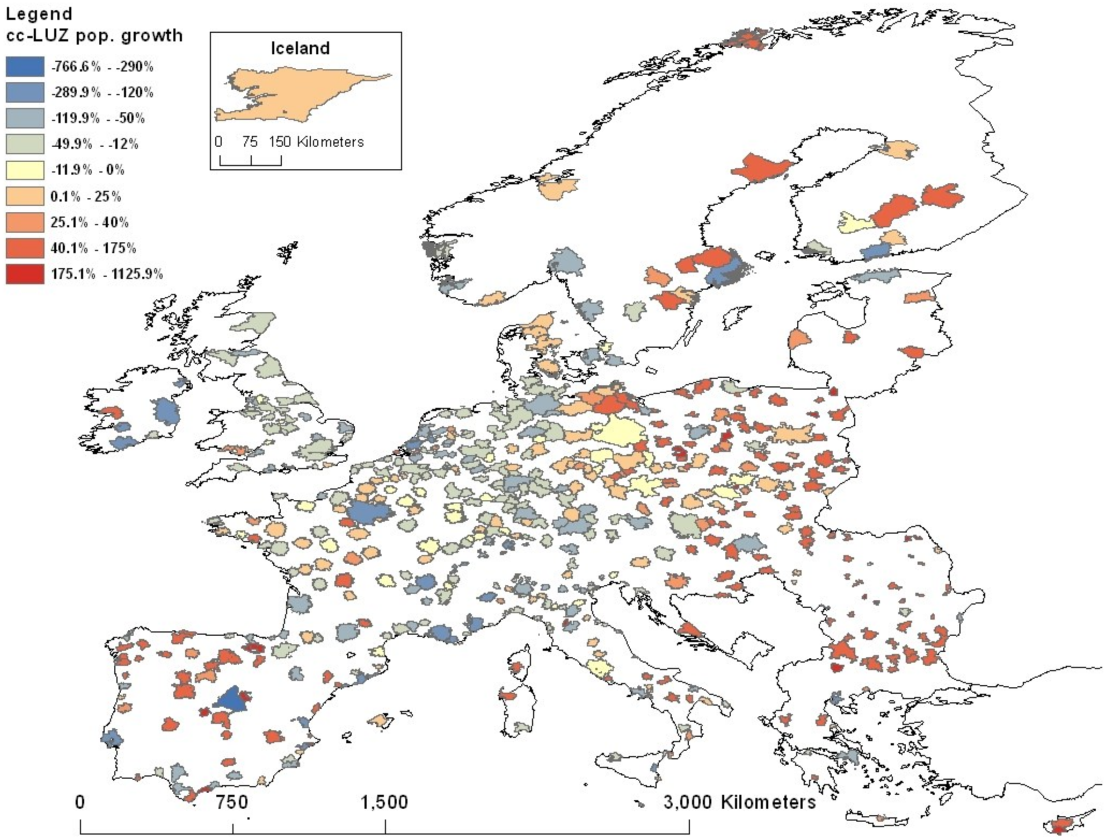
Table 2: Quartile Population Growth and Relative Suburbanization

Quartiles (LUZ 1961 population)	1st	2nd	3rd	4th
Population classes	(23,892-111,673)	(111,674-178,017)	(178,018-343,067)	(343,067-10,618,868)
LUZ Population Change (thousands)	8,200	8,700	14,500	46,000
CC Population Change (thousands)	6,515	5,900	7,200	8,200
Suburban Population Change (thousands)	1,760	2,833	7,300	37,800
Relative Population Change (thousands)	4,755	3,067	-100	-29,600
LUZ Population Growth	71.93%	42.23%	40.96%	29.30%
CC Population Growth	98.92%	50.00%	39.34%	9.49%
Suburban Population Growth	36.79%	32.31%	42.69%	53.85%
Relative (Sub)urbanization	62.14%	17.69%	-3.35%	-44.36%

Finally, another useful descriptive measure of the pattern of relative suburbanization in Europe can be obtained by the map 1 below. As it can be confirmed by the map, most of the capital cities and big cities experienced relative suburbanization in general. Another pattern which can be observed is that cities in East European and Southern countries experienced significant relative urbanization during the time that the cities of central Europe decentralised[21].

[21] van den Berg et al. (1982) related this pattern with the subquential phases of urban development, identifying the area that experienced relative suburbanization as the industrial cities founded during the Industrial Revolution.

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



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4 The evolution of transport infrastructure in Europe

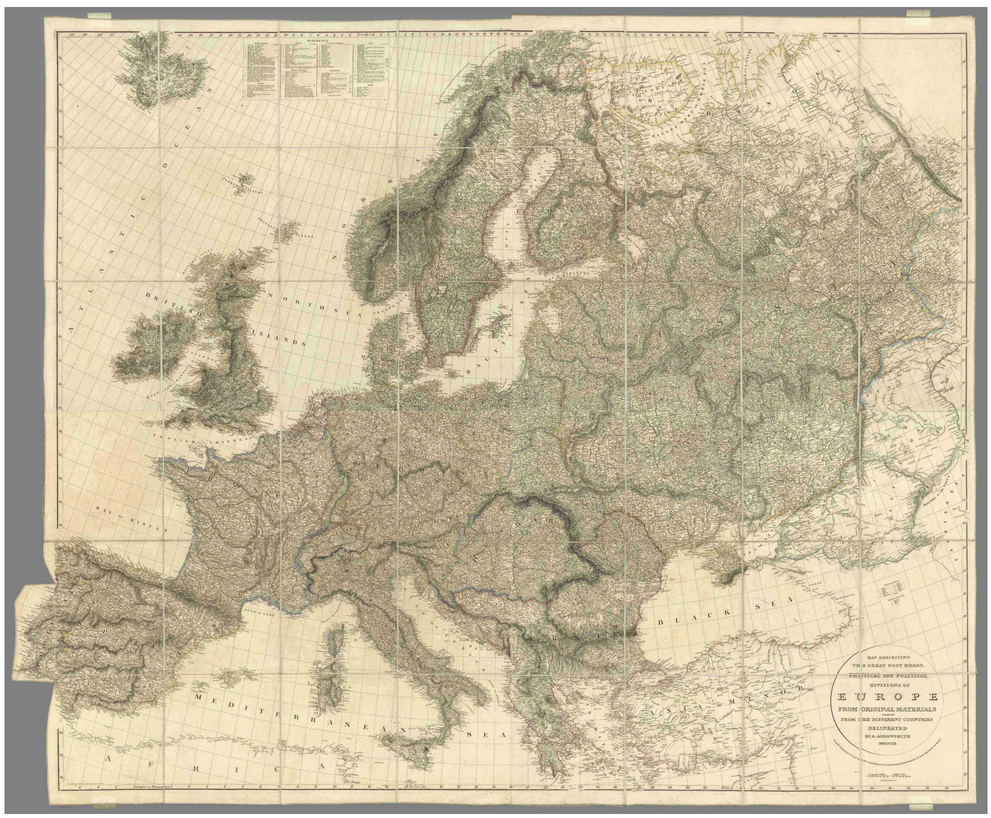
In this section, we describe the evolution of the modern transport network in Europe. The starting point of this evolution approximately coincides with the creation of the historical transport infrastructure network that we use to instrument the modern infrastructure variables. By describing this evolution, we discuss the assumption of instrument validity intuitively. The instrument relevance is tested empirically in section 5.1 where the first-stage estimations are presented. We start by discussing the highway network and then we move to the railroads.

4.1 Post routes in 1810 and 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 17th century, governments realized that an improved road system could foster economic prosperity, better governance and could facilitate the creation of a reliable postal system. Post road systems were developed throughout Europe during the 17th and 18th centuries.

Notwithstanding roads remained relatively primitive until the middle of the 18th century, in the last quarter of the eighteenth 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 19th 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 19th century when railroads became the primary mode of transportation (Elias, 1981, 1982).

Figure 2: Post Routes in Europe in 1810.



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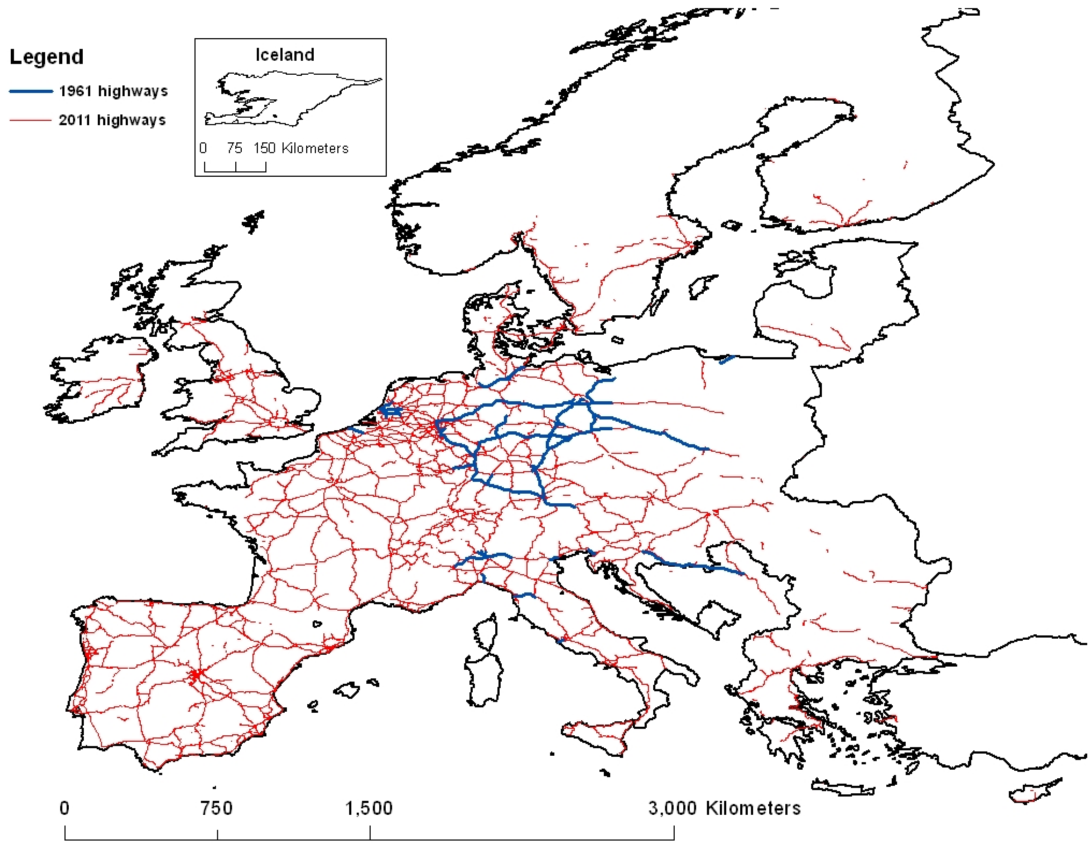
Source: David Rumsey Historical Map Collection

Very few 19th 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 areas where the natural landscape allows it, modern highways have followed their path. These two facts provide evidence that both the assumptions of instrument exogeneity and instrument relevance can be claimed very convincingly. Therefore, the main post roads in 1810 seem to be a valid instrument that provides exogenous variation for the unbiased estimation of our endogenous variable of highway rays.

Figure 3 below depicts the evolution of the highway network in Europe between 1961 and

2011. In 1961, there were only very few highways mainly concentrated in Germany and partly in Italy. By 2011 though, the highway network had extended almost everywhere over the European continent. The fact that in 1961 there was hardly any highway network in Europe allows us to use the absolute number of highway rays in 2011 as our dependent variable in equation (1) below, instead of the difference of the number of highway rays between 1961 and 2011[22].

Figure 3: Evolution of highways (1961-2011)



4.2 Railroads in 1870 and modern railroads

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 1960, 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 fact that the railway network in Europe has such a long history highlights its importance.

[22]We also use the highway rays differences and the existing 1961 highway rays in the estimation section but the results do not change.

Figure 4a: The railway network in 1870.

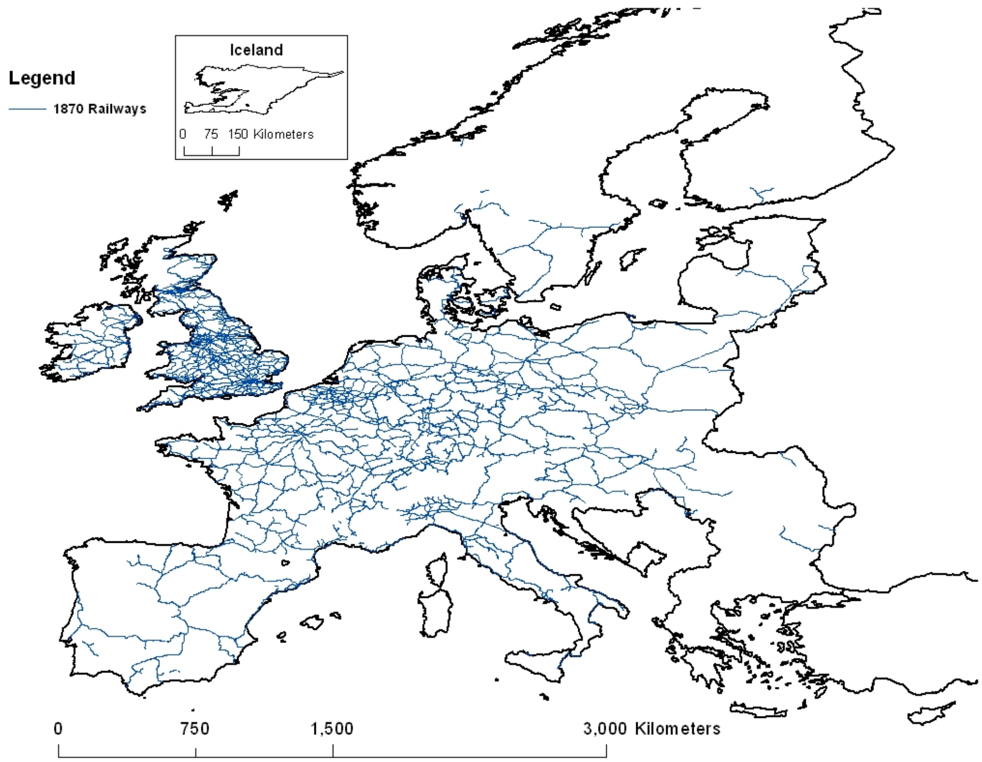


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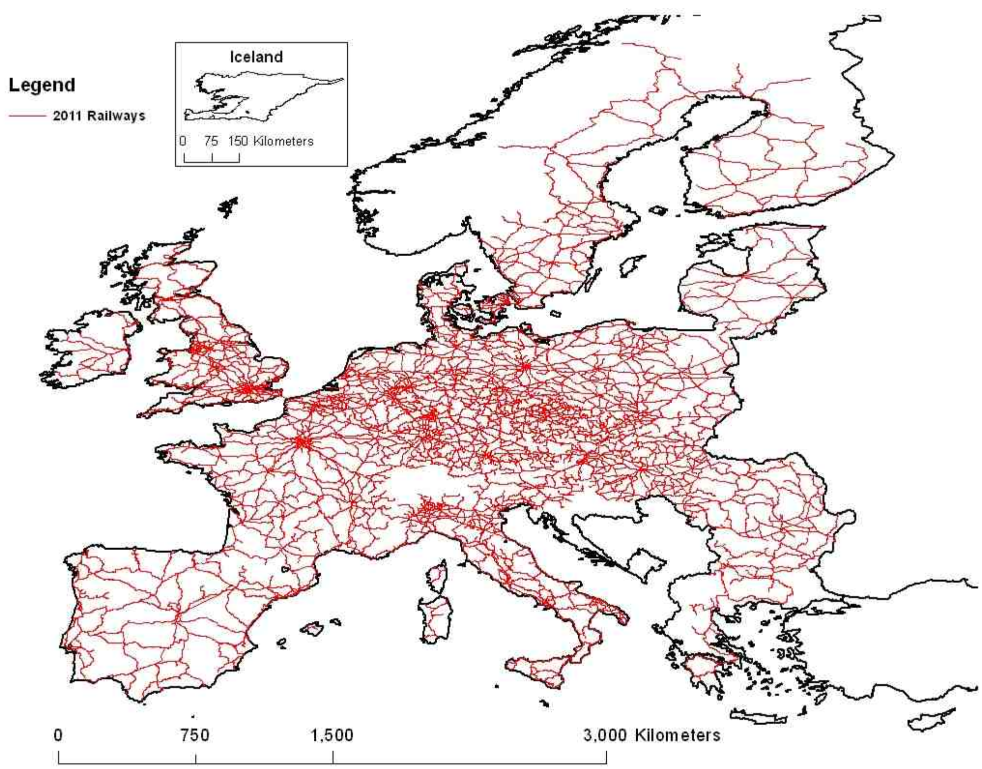
Figure 4b: The railway network in 2011.



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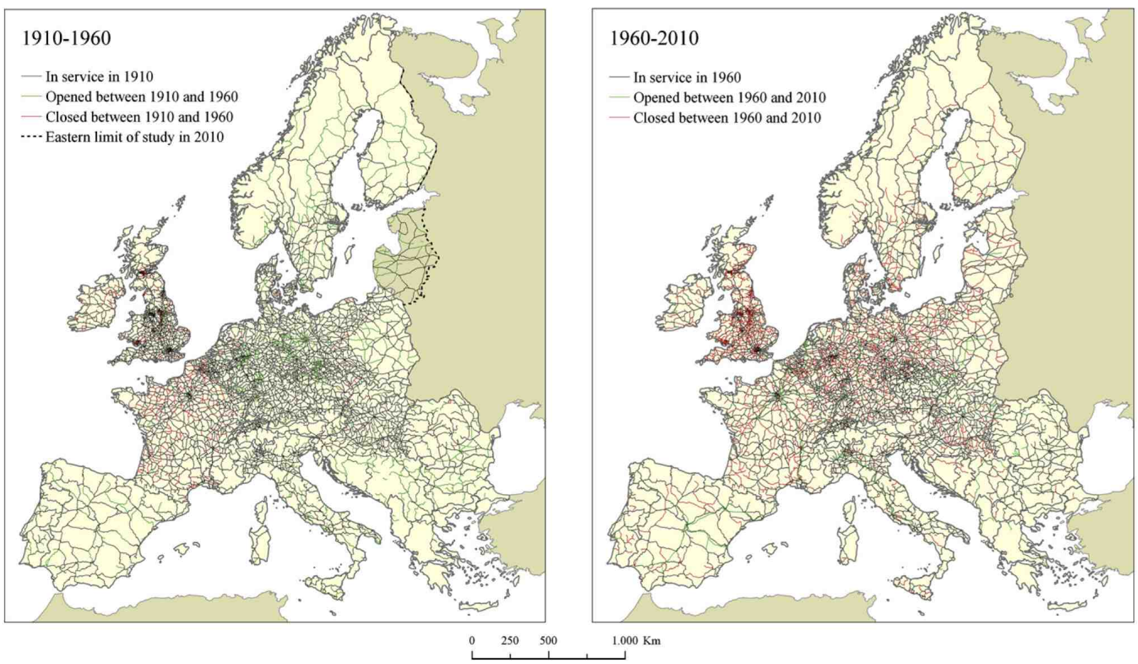
As it can be shown by the maps above, by 2011, the rail network had expanded almost everywhere in the European territory. However, in the period 1910-1960, numerous lines closed while some new lines were created (Martí-Henneberg, 2013). These 20th century changes in the rail network were mainly localised in the Central-North Europe, where the first railways in Europe were constructed. In some cases, these changes were driven by the underlying political factors[23]. However, what is important for the objectives of this paper is the number of lines closed and lines opened between 1870 and 2011 that can be seen in the map in figure 5 below. These radical changes in the rail network between 1870 and 2011 provide evidence that the existing railway network in 1870 did not affect directly the population change in european central cities between 1961 and 2011. At the same time, as it can be seen by the maps 4a and 4b, and by the first stage estimations below (section 5.1), the railway rays in 1870 explain the modern radial railways in 2011. Therefore, the instrument validity assumption can be claimed for the case of 1870 railway rays too.

Figure 5: Evolution of the railway network in Europe (1910-2010).



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Source: Martí-Henneberg (2013)

5 Estimation

5.1 First-stage results

The main issue with the estimation of the specifications (1) and (2), presented in section 2, is the potential endogeneity which may rise as a result of simultaneous causality bias between the trans-

[23]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.

port infrastructure variables and the population change in the core cities. As it has been argued in the literature (Baum-Snow, 2007; Garcia-López et al., 2013), 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. In order to address this endogeneity issue, we use two-stage least squares (TSLS) regressions using instrumental variables (IV) in order to estimate the causal effect of the transport infrastructure improvements on the core city population change. In this section, we present the first-stage estimates which show that the historical transport infrastructure variables, that we use as a source of exogenous variation for our main independent variables of interest, can explain the modern transport network.

As it can be seen in table 3 below, both these historical transport variables that we have included as instruments are highly significant in explaining the modern transport infrastucture. These coefficients were estimated controlling for a series of geographical variables that may have affected the location of modern 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 kilometers 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[24].

Table 3: Location of modern transport variables as a function of historical.

Panel A Highway rays			**Panel B** Radial railways		
Dependent variable: 2011 highway rays	OLS [1]	OLS [2]	Dependent variable: 2010 radial railways	OLS [3]	OLS [4]
Post route rays 1810	0.177^a (0.043)	0.158^a (0.046)	Rail rays 1870	0.728^a (0.091)	0.706^a (0.096)
ln(CC land area)	Y	Y	ln(CC land area)	Y	Y
ln(LUZ land area)	Y	Y	ln(LUZ land area)	Y	Y
1961 ln(suburban pop.)	Y	Y	1961 ln(suburban pop.)	Y	Y
1961–2011 Δln(LUZ pop.)	Y	Y	1961–2011 Δln(LUZ pop.)	Y	Y
Geography	Y	Y	Geography	Y	Y
History	Y	Y	History	Y	Y
Urban Amenities	N	Y	Urban Amenities	N	Y
Country FE	Y	Y	Country FE	Y	Y
Observations	579	**570**	Observations	579	**570**
Adjusted R^2	0.59	0.60	Adjusted R^2	0.65	0.65
First-stage stat.	16.58	11.72	First-stage stat.	64.22	54.33

Notes: Geography variables are the logarithm of the distance, altitude, index of terrain ruggedness, and elevation range. History is controlled by the inclusion of the logarithm of the city population in 1850. Urban amenities are the ratio of urban green area in the central city and in the suburbs, for the existence of an historical city centre or another landamrk denominated by UNESCO and for the existence of a university in a city before 1960. When urban amenities are included Greek cities are excluded from our sample since Corine land use data are not available. Robust standard errors are are in parentheses. Clustering standard errors by country does not affect most estimated coefficients. ^{a}, ^{b}, and ^{c} indicates significant at 1, 5, and 10 percent level, respectively.

[24]See for example Aw (1981), Highway Research Board (1962) and Paterson (1987).

In addition, by controlling for historical population, we avoid potential omitted variable bias, which could arise due to the fact that the historical population may have affected both the historical transport variables and the allocation of modern highways. The inclusion of historical population is a factor that captures the past economic development of a city as well, as it has been argued by De Long and Shleifer (1993) and Acemoglu et al. (2005). Moreover, we use country fixed effects in order to control for country-specific observable and unobservable socio-economic, institutional, cultural and political characteristics that may have affected both the allocation of the historical and the modern transport infrastructure variables. Finally, in specifications [2] and [4], we include urban amenities variables in order to control for "more history" (UNESCO landmarks, old universities) that may have affected the allocation of both historical and modern transport networks.

While the coefficients for both highway and railway first-stage estimations (in Panel A and B respectively) are highly significant, the coefficients for highways and railways are quite different between them. The coefficient for the main post routes is relatively low compared to that for the radial railways in 1870. This could raise some concerns about the exogeneity of this variable as it seems to be almost the same with the modern rail variables. However, as we argued in section 4a, the railway network of 1870 was changed substantially until 2010 with many lines closing and others opening. Apparently, many new lines were allocated in such a way that they substituted the lines that closed, a fact that is reflected in the value of the historical railway rays' coefficient. When the robustness analysis is completed we will use a *placebo straight line railway network*, simulated based on the historical urban structure, which we can reproduce using our historical population dataset.

5.2 Main second-stage results

In this section, we study whether highway and railway rays have caused suburbanization and to what extent, by estimating the causal relationship between transport infrastructure and the central city population growth in the period 1961-2011. We begin by analyzing the role of highway rays on central city population change and then we turn our focus on the effect of radial railways. In the following two sections we will present and discuss the estimations of the two different types of transport infrastructure.

5.2.1 Did highways cause suburbanization?

Table 4 below presents our main results for the effect of modern highways on the change in the logarithm of central city population during the period 1961-2011. The first two columns present the OLS estimates. Column [1] shows the estimated effect of highways on central city population change when we do not take into account any other variables that may have affected this change. In column [2], we can see the estimated effect when we control for all the available control variables, except for the urban amenities. Both specifications show a significant and negative effect of highway rays on population change as we expected from the theory and the previous studies. However, these estimates are susceptible to simultaneous causality bias, as we discussed earlier.

Columns [3] to [9] show the results of a TSLS estimation, where the main post routes in 1810 are used as a source of exogenous variation for the highway rays in 2011. Column [3] shows again the basic specification without any control variables. As we can observe, the absolute value of the coefficient for highway rays is quite higher than the estimated coefficient in column [1], confirming our concern for endogeneity in the OLS regressions. By controlling for the area variables, we focus on the effect of highway rays on *population density* rather than on the population change irrespective of the size of the central city and that of the LUZ. By including the change in the logarithm of population in the whole LUZ area, we account for the change in the logarithm of population in the city centre that may be the result of other factors that have increased the attractiveness of the LUZ as a whole. Finally, by controlling for the logarithm of initial population in the suburbs, we control for the fact that the observed population change may be affected by the level of city population in the beginning of the period we analyse[25].

Table 4: The effect of modern highways on CC population change.

Dependent variable: 1961–2011 Δln(CC pop.)	OLS [1]	OLS [2]	TSLS [3]	TSLS [4]	TSLS [5]	TSLS [6]	TSLS [7]	TSLS [8]	TSLS [9]
2011 highway rays	-0.043^a	-0.028^a	-0.069^a	-0.091^a	-0.108^a	-0.096^b		-0.104^b	-0.104^b
	(0.007)	(0.006)	(0.019)	(0.029)	(0.034)	(0.041)		(0.044)	(0.043)
2011–1961 Δ(highway rays)							-0.099^b		
							(0.043)		
1961 highway rays							-0.059^b		
							(0.027)		
ln(CC land area)	N	Y	N	Y	Y	Y	Y	Y	Y
ln(LUZ land area)	N	Y	N	Y	Y	Y	Y	Y	Y
1961–2011 Δln(LUZ pop.)	N	Y	N	Y	Y	Y	Y	Y	Y
1961 ln(suburban pop.)	N	Y	N	Y	Y	Y	Y	Y	Y
Geography	N	Y	N	N	Y	Y	Y	Y	Y
History	N	Y	N	N	N	Y	Y	Y	Y
Urban Amenities	N	N	N	N	N	N	N	N	Y
Country FE	Y	Y	Y	Y	Y	Y	Y	Y	Y
Observations	579	579	579	579	579	579	579	**570**	**570**
R-squared	0.47	0.72	0.46	0.73	0.72	0.74	0.74	0.74	0.75
First-stage stat.			71.2	33.1	27.1	16.6	16.2	15.2	11.7

Notes: Geography variables are the logarithm of the distance to coast from the CC centroid, altitude, index of terrain ruggedness, and elevation range for CC and LUZ. History is controlled by the inclusion of the logarithm of the city population in 1850. Robust standard errors are are in parentheses. Urban amenities are the ratio of urban green area in the central city and in the suburbs, for the existence of an historical city centre or another landamrk denominated by UNESCO and for the existence of a university in a city before 1960. When urban amenities are included Greek cities are excluded from our sample since Corine land use data are not available. Clustering standard errors by country does not affect most estimated coefficients. ^{a}, ^{b}, and ^{c} indicates significant at 1, 5, and 10 percent level, respectively.

In specification [5], we also control for central city and LUZ geography. In particular, we control for the elevation mean and range and for the mean ruggedness of the surface for both the central city and the LUZ as a whole. In addition, we control for the logarithm of the distance between the LUZ centroid and the closest coastline. This last variable seems to have a highly significant and positive impact on the population change in the central cities. This effect can be explained by the fact that coastal cities have the sea as a natural barrier that limits their expansion potential. This positive influence of distance to the coast magnifies the absolute value of the effect of highway rays on central city population change. It should be noted that as we discussed earlier, controlling

[25]The reason we use suburban population rather than population in the LUZ is to avoid endogeneity issues.

for geography is very important because it affects both the allocation of the motorways and the population change in the central cities.

In column [6], we also control for the logarithm of city population in 1850. This variable captures a *path dependence* effect i.e. the past population may have driven modern population changes. This variable is significant for both stages of the estimation. We consider specification [6] our preferred specification. The value of this coefficient suggests that an additional highway ray caused a 9.5% decline of the average central city population growth in the period 1961-2001 (50 years). This outcome is more or less in line with the ones estimated in the recent empirical literature (Baum-Snow, 2007; Baum-Snow et al., 2013; Garcia-López et al., 2013) for the cases of US, China and Spain, which were estimated at 18% (in 40 years), 5% (in 20 years) and 8% (in 50 years) respectively.

In specification [7], we use the difference of the number of highway rays between 2011 and 1961 and the stock of highways in 1961 to control for the fact that the coefficient we estimated in columns [1]-[6] may be the result of the existing highway network in 1961. The main coefficient of interest remains virtually the same, whereas the coefficient for the number of 1961 highway rays shows that one additional highway ray of the existing highway network in 1961 caused a 5.9% reduction in the central city population growth of the average city in these 50 years.

In column [9], we control for some urban amenities that could have affected the population growth of the central cities in Europe. Column [8] is only included to show that the change of the highway rays' coefficient in [9] is not the result of the inclusion of urban amenities but rather the result of changing our sample because of the unavailability of the green space data for Greece. The reason we include the ratio of urban green area is to control for the fact that in the suburbs there is more green space in general. By including this ratio for the core city and the suburbs, we control for the fact that suburbanization may be driven by the residents' preferences for green space rather than the decrease of the commuting cost. Then, we control for the aesthetic/cultural value of a central city. The existence of such an aesthetic/cultural value in a central city may affect the decision of the households to move or not to the suburbs. Finally, the inclusion of the university dummy as another control variable for urban local amenities is justified because students are not expected to use cars and therefore we expect that highways did not affect so much the suburbanization process in cities with universities. As the seminal paper of (Glaeser and Kahn, 2004) argues, "while many factors may have affected urban sprawl, it ultimately has only one root cause: the automobile". When we include all the aforementioned local urban amenities controls, our main results do not change as it can be seen in the column [9] of the table 4 above.

5.2.2 Did railways cause suburbanization too?

In this section, we turn our attention on the causal effect of radial railways on central city population change. We will follow the same specifications as the ones we estimated for highway rays. The estimation output is presented in the estimation table 5 below.

In table 5, the estimated coefficient for the effect of railway rays on central city population change has the expected sign and is highly statistically significant. In particular, the first two columns ([1] and [2]) show the OLS estimates. In column [3], the estimates of the TSLS-IV approach are presented. Once again, when we address the endogeneity concerns, the coefficient ”jumps”, confirming the endogeneity concerns. As in the previous section, we proceed by adding control variables until we get to our preferred specification (column [6]). The estimated coeffecient in [6] shows that an additional railway ray in the stock of 2011 caused central city population growth of an average city to decline by 2.5%. Once again, in [8] we include the urban amenities variables but the estimated coefficient of interest barely changes with respect to [7].

Table 5: The effect of modern railways on CC population change.

Dependent variable: 1961–2011 Δln(CC pop.)	OLS [1]	OLS [2]	TSLS [3]	TSLS [4]	TSLS [5]	TSLS [6]	TSLS [7]	TSLS [8]
2010 radial railways	-0.028[a]	-0.007	-0.036[a]	-0.026[b]	-0.035[a]	-0.025[b]	-0.028[b]	-0.027[a]
	(0.007)	(0.006)	(0.010)	(0.010)	(0.013)	(0.013)	(0.014)	(0.010)
ln(CC land area)	N	Y	N	Y	Y	Y	Y	Y
ln(LUZ land area)	N	Y	N	Y	Y	Y	Y	Y
1961–2011 Δln(LUZ pop.)	N	Y	N	Y	Y	Y	Y	Y
1961 ln(suburban pop.)	N	Y	N	Y	Y	Y	Y	Y
Geography	N	Y	N	N	Y	Y	Y	Y
History	N	Y	N	N	N	Y	Y	Y
Urban Amenities	N	N	N	N	N	N	N	Y
Country FE	Y	Y	Y	Y	Y	Y	Y	Y
Observations	579	579	579	579	579	579	**570**	**570**
R-squared	0.46	0.78	0.46	0.75	0.76	0.78	0.77	0.79
First-stage stat.			116.5	86.6	64.6	64.2	57.0	54.3

Notes: Geography variables are the logarithm of the distance to coast from the CC centroid, altitude, index of terrain ruggedness, and elevation range for CC and LUZ. History is controlled by the inclusion of the logarithm of the city population in 1850. Urban amenities are the ratio of urban green area in the central city and in the suburbs, for the existence of an historical city centre or another landamrk denominated by UNESCO and for the existence of a university in a city before 1960. When urban amenities are included Greek cities are excluded from our sample since Corine land use data are not available. Robust standard errors are are in parentheses. Clustering standard errors by country does not affect most estimated coefficients. [a], [b], and [c] indicates significant at 1, 5, and 10 percent level, respectively.

6 Robustness Analysis

In this section we run some tests in order to confirm the robustness of our estimations. columns -[1] and [5] show our preferred specifications for the highways and the railroads, respectively. One important endogeneity concern that has been highlighted in the literature (Baum-Snow, 2007; Garcia-López et al., 2013) is the reverse causality between the central city population change and the LUZ population change[26]. Given that the difference of the LUZ population is an important control in our analysis, we cannot exclude this variable. Therefore, in a similar way as Glaeser et al. (2001), we use climate conditions captured by the mean temperature in the LUZ as an instrument for the LUZ population change between 1961 and 2011. The instrument relevance assumption seems to be satisfied since based on Glaeser et al. (2001), ”wheather is the single most important population growth determinant in the US at the country level”. The exogeneity of the instrument seems to be satisfied intuitively too. The rationale behind this argument is that the choice of the city to live by a household is expected to be related to the wheather but not that the average temperature in the LUZ area may directly affect the household decisions to live in the central city

[26] Both these variables actually refer to the change in the logarithm of population.

or the suburbs of that LUZ. In columns [2] and [5] of table 6 below, we instrument both 2011 transport infrastructure variables and the change in the logarithm of LUZ population between 1961 and 2011 and our main estimate hardly changes[27].

Another consideration could be that the degree of suburbanization, being a decision of relocation, is affected by a sorting mechanism based on the matching of the population's preferences and the provision of local public goods and services in each local jurisdiction (Tiebout, 1956). This is why in columns [3] and [7] we control for the number of municipalities in the LUZ areas, as a proxy of the number of Tiebout sorting options available. As it can be seen, the estimated coefficient for highway rays is somewhat lower. This change though is driven by the importance of the municipalities' variable for the first-stage rather than for the second stage. The coefficient for radial railways remains virtually unchanged and statistically significant. Finally, another consideration is to include the inverse distance from each LUZ centroid to the nearest LUZ multiplied by the logarithm of LUZ population in that nearest LUZ. We include this variable in order to control for the influence of "satellite cities", in the sense that the population decline in a central city may be driven by the fact that people moved to a satellite city nearby instead of the suburbs. Therefore, as a partial test for the general equilibrium effects among LUZ, in columns [4] and [8], we include this proxy variable. Once again, our estimated coefficients of interest are roughly the same.

Table 6: Robustness Results.

Panel A Highway rays					**Panel B** Radial railways				
Dependent variable: 2011 highway rays	TSLS [1]	TSLS [2]	TSLS [3]	TSLS [4]	Dependent variable: 2011 highway rays	TSLS [5]	TSLS [6]	TSLS [7]	TSLS [8]
2011 highway rays	-0.096^b (0.041)	-0.092^b (0.041)	-0.100^b (0.043)	-0.095^b (0.041)	2011 radial railways	-0.026^b (0.013)	-0.025^c (0.013)	-0.026^b (0.013)	-0.026^b (0.013)
ln(CC land area)	Y	Y	Y	Y	ln(CC land area)	Y	Y	Y	Y
ln(LUZ land area)	Y	Y	Y	Y	ln(LUZ land area)	Y	Y	Y	Y
1961 ln(suburban pop.)	Y	Y	Y	Y	1961 ln(suburban pop.)	Y	Y	Y	Y
1961–2011 Δln(LUZ pop.)	Y	Instr.	Y	Y	1961–2011 Δln(LUZ pop.)	Y	Instr.	Y	Y
Geography	Y	Y	Y	Y	Geography	Y	Y	Y	Y
History	Y	Y	Y	Y	History	Y	Y	Y	Y
ln(LUZ municipalities)	N	N	Y	N	ln(LUZ municipalities)	N	N	Y	N
Satellite cities	N	N	N	Y	Satellite cities	N	N	N	Y
Country FE	Y	Y	Y	Y	Country FE	Y	Y	Y	Y
Observations	579	579	579	579	Observations	579	579	579	579
Adjusted R^2	0.74	0.75	0.74	0.74	Adjusted R^2	0.77	0.59	0.77	0.77
First-stage stat.	16.58	**9.04**	14.81	16.39	First-stage stat.	62.06	**16.84**	67.91	61.97

Notes: Geography variables are the logarithm of the distance, altitude, index of terrain ruggedness, and elevation range. History is controlled by the inclusion of the logarithm of the city population in 1850. Robust standard errors are are in parentheses. Clustering standard errors by country does not affect most estimated coefficients. ^{a}, ^{b}, and ^{c} indicates significant at 1, 5, and 10 percent level, respectively.

[27] The first-stage F-statistic might be below Stock and Yogo's rule of thumb, but it is actually above 7.03 that is Stock and Yogo's weak identification test critical values for 10% maximal IV size.

7 Work in Progress

As discussed in the Introduction section, this preliminary version is still incomplete. At this moment, we are working on estimating the suburbanization effect for different types of roads (national roads, trunk roads etc.) that are available in our dataset. Another consideration is to use the public transit (metro) data instrumented by the consistency of the soil[28]. Furthermore, we are trying to find strong instruments that will allow us to estimate the effect of both highways and railways jointly. Regarding the robustness analysis, we are in the process of using OECD's *Functional Urban Areas* definition instead of Eurostat's *Large Urban Zones*. In addition we need to find another strong instrument to test whether highway ray results are driven or not by length results. For railroads, we will test for network length and for the station locations.

The estimation that we previously discussed is not the unique goal of this paper. The goal of this paper is fourfold. As we have discussed in our data section, the degree of relative (sub)urbanization differs substantially among the different periods of time, among different city sizes and among different geographical areas of Europe. We will extend this paper, by employing this intrinsic heterogeneity of the phenomenon under study, in order to estimate the effect of highway and railway rays for different geographical regions of Europe[29]. Furthermore, we will include the polycentricity of the major European cities and we will estimate the effect of highway and railway penetration on the population change of these sub-centres. Finally, we want to estimate the effect of locating a highway ramp within the borders of a municipality on the population change in these municipalities using a diff-in-diff and an IV research design.

[28]see `http://www.eea.europa.eu/data-and-maps/figures/soil-map`

[29]One such group is the group of regions that are catalogued as *Objective 1 regions* (regional GDP per capita less than 75% of the EU average), which received the highest EU funding. Another grouping will be based on the distinct European integration phases

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