Job decentralization, subcenter formation and public transportation

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ABSTRACT: There is recent evidence that concludes that transportation's improvements within metropolitan areas have a clear effect on population and job decentralization processes from the central cities to their suburbs. But nothing has been said on how those improvements affect the spatial organization of the economic activity in the suburbs. This paper analyses the effects of transportation's changes on the employment subcenters formation. With data from metropolitan Paris between 1968 and 2010, we first show that rail network improvements cause the expected job decentralization by attracting jobs to non-central Parisian suburban municipalities. But our innovative results show that the new rail transit clearly affects the organization of employment through the number and size of the employment subcenters. The presence of a rail station increases the probability of a suburban municipality of being an employment subcenter by 5%. The results are heterogeneous depending on the suburban train characteristics.

Key words: urban spatial structure, decentralization, subcenters, transportation
JEL classification: R4, O2

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1. Introduction

Over the last fifty years metropolitan Paris has been undergoing a process of employment decentralization. Simultaneously, national and regional goverments have dedicated huge amount of money to fund public transportation, in particular in its rail transit network. In this paper, we investigate Paris' job decentralization and the role played by rail transit between 1968 and 2010. In particular, we are interested on studying the effects of transit on subcenter formation.

We organize our investigation in three parts that aim to answer three questions. First, we study the effects of transit on the intrametropolitan distribution of employment: Does rail transit foster local employment growth and decentralization in metropolitan Paris? Our preliminary results show that (1) there is concentration around transit (employment growth increases with proximity to rail stations), and (2) transit causes job decentralization (employment growth in central Paris reduces with proximity to rail stations).

Second, we analyze the spatial pattern of job decentralization: Is Paris decentralization diffuse or clustered around subcenters? Using Daniel P. McMillen nonparametric approach (McMillen, 2001), we identify employment subcenters in six census years between 1968 and 2010. Our preliminary results show that (1) the number of subcenters increases from 21 in 1968 to 35 in 2010, (2) some municipalities emerge and others dissappear as (part of) subcenters between 1968 and 2010, and (3) the absolute and relative growth of employment in the subcenters is very intense and important. As a result, it seems that the spatial pattern of job decentralization in Paris is reinforcing the polycentric nature of its urban spatial structure.

Finally, we investigate the role played by transit on the emergence of employment subcenters: Does rail transit cause subcenter formation? This is the key question that we want to anskwer and our contribution to literature. Our preliminary results show that the answer is 'yes': (1) the presence of a rail station increases the probability of a suburban municipality of being (part of a) subcenter by 5%, and (2) a 10% increase in municipality proximity to a suburban station causes about a 3% increase in its probability of being (part of) a subcenter. While these results are robust to subcenter size and definition, we do find that the effects are heterogeneous in terms of the type of rail: the suburban train and the Regional Express Rail (RER). In particular, the effects for suburban train are similar to the above mentioned average results. However, the RER effects are much higher: the presence of a RER station and a 10% increase in municipality proximity to this type of stations increases the probability of being (part of) a subcenter by a 10% and around a 5%, respectively.

Summarizing, we investigate the effects of rail transit on subcenter formation in metropolitan Paris between 1968 and 2010. We find that improvements to the rail network cause job decentralization and influence the spatial pattern of decentralized employment by attracting jobs to non-central suburban municipalities that become (part of) subcenters.

Our investigation is of interest for, at least, three reasons. First, while there is some evidence of the existence of employment subcenters (see, for example, McMillen, 2001, McMillen and Smith, 2003), '(...) little is known about the details of the spatial patterns of decentralized employment (...)' (Duranton and Puga, 2015) and, in particular, '(...) still hardly studied is why subcenters form (...)' (Mills, 2000, p. 18). As far as we know, we are the first to track the formation of subcenters in a 50-year period and the first to empirically study the role played by transportation improvements.

Second, this research also furthers our understanding of the role of transportation infrastructure on shaping cities. While studies by Baum-Snow (2007, 2010), Baum-Snow, Brandt, Henderson, Turner, and Zhang (2013) and Garcia-López, Holl, and Viladecans-Marsal (2015*b*) show that transportation causes population and employment decentralization, our results indicate that transportation also influences the spatial pattern of decentralized employment by fostering the emergence of subcenters.

Finally, we follow recent literature that highlights the identification issue that this type of studies has to face: the simultaneous determination of employment location and growth and transportation improvements. Following, Duranton and Turner (2012), Garcia-López (2012), Baum-Snow *et al.* (2013) and Garcia-López *et al.* (2015*b*), we rely on a Instrumental Variable strategy based on 'historical' instruments built with Paris' 1870 railroad network.

2. Does rail transit foster local growth and decentralization?

The main purpose of our paper is to establish whether rail transit causes subcenter formation. Prior to answering this question, we need to assess the role played by rail transportation in employment growth and in the decentralization process in the Paris metropolitan area.

2.1 Growth, decentralization and rail transit in the Paris metropolitan area

The Paris metropolitan area at a glance. This study focuses on the Paris metropolitan area, a French region known as *Ile de France*. Composed of 1,300 municipalities, it is the densest and most populated metropolitan area in France, with 981 inhabitants per square kilometer in 2010 for a total of 11,786,234 inhabitants, and is as well the region with the highest employment density, with a total of 5,668,902 jobs in 2010 (21.6% of French employment).

Relying on detailed population and employment data at the municipal level from six census waves (1968, 1975, 1982, 1990, 1999 and 2010), we are able to track the evolution of the urban spatial structure of the Paris metropolitan area over the past forty years. We also use precise transportation data, provided by Mayer and Trévien (2015) and the IAU, to characterize the changes in the area's public transportation over the period.

This area presents two interesting features for our analysis that we briefly describe next: (1) it is undergoing a process of employment decentralization in which its central city (Paris) loses jobs in favor of suburban locations, and (2) its public transportation infrastructure is based on a rail transit network that has been dramatically improved since the 1960s.

Growth and decentralization in the Paris metropolitan area. Table 1 shows the evolution of jobs in the Paris metropolitan area between 1968 and 2010, distinguishing between the CBD and other municipalities. The first line reveals that the area as a whole grew by about one third over the period. More importantly, the decomposition of the area into the CBD and other municipalities clearly shows that it has undergone an employment decentralization process, both in absolute and relative terms: not only has the number of jobs in the CBD decreased by 7.1% over the period, but the relative weight of the CBD has also dropped from 45.3% of the metropolitan area jobs in 1968 to 31.7% in 2010.

Table 1: Employment trends in metropolitan Paris, 1968–2010

	1968	1975	1982	1990	1999	2010	1968–2010
Metropolitan area	4,277	4,675	4,705	5,076	5,042	5,669	1,392 (32.6%)
CBD (municipality of Paris)	1,936	1,918	1,808	1,815	1,601	1,798	-138 (-7.1%)
MA share	45.3%	41.0%	38.4%	35.8%	31.8%	31.7%	
Suburban municipalities	2,341	2,757	2,897	3,261	3,441	3,871	1,530 (65.4%)
MA share	54.7%	59.0%	61.6%	64.2%	68.2%	68.3%	

Note: Employment values are thousands of jobs. Growth rates are in parentheses.

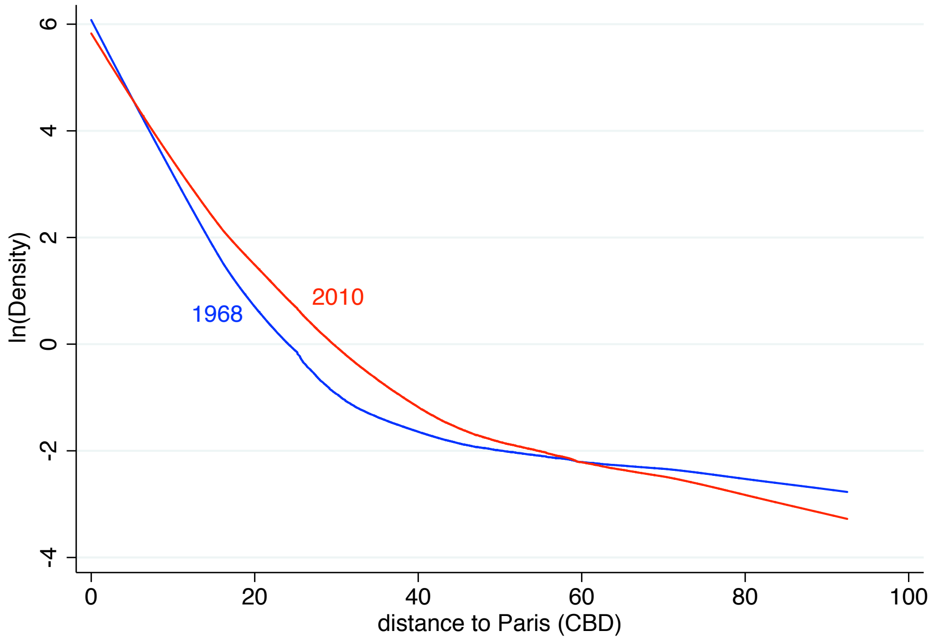
Additional evidence of this decentralization process comes from estimating the traditional monocentric density function for each year. Using municipal data (and *arrondissement* data for Paris municipality), we regress the log of employment density on the distance to the center of the CBD (Paris). In order to take nonlinearities into account, our estimations are based on a nonparametric method known as Locally Weighted Regression (LWR), with a bandwidth of 0.5 [1] (McMillen, 2001).[2]

The LWR density estimates drawn in 1 clearly illustrate the decentralization process between 1968 (blue line) and 2010 (red line). Indeed, between these two dates, employment density in the most central municipalities (0 to 10 km from the CBD) decreased, while it increased in municipalities located between 10 and 60 km from the CBD, in line with a decentralization of jobs from the CBD towards suburban municipalities. We can also note a reduction in employment density for the most peripheral (mostly rural) municipalities (more than 60 km from the CBD). This, combined with the increase observed for the suburban municipalities indicate the emergence of new suburban subcenters (and reinforcement of existing ones).

[1] A window size of 0.5 means that the nearest 50% of observations are weighted.

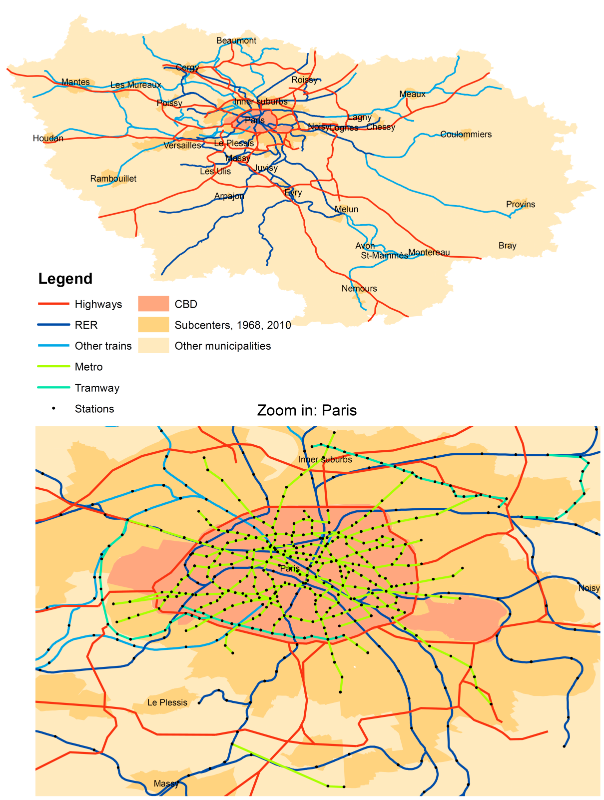
[2] Results are similar when using window sizes of 0.1, 0.3, 0.8 and 1.0 and are available upon request.

Figure 1: Employment decentralization in metropolitan Paris, 1968–2010



Note: Density estimates based on LWR with a window size of 0.5.

Figure 2: Transportation infrastructures in metropolitan Paris, 2010



The recent improvement of rail transit in the Paris metropolitan area. The transportation infrastructure of the Paris metropolitan area today is mostly based on a railroad network made of more than 1,600 km of lines (Figure 2) and including four network types. First, a suburban train (henceforth *train)* connecting Paris to the rest of the metropolitan area (suburbs as well as some of the most remote rural municipalities), that underwent substantial improvement over the 1960s.

Second, the Paris region is endowed with a regional express network (*Réseau Express Régional* in French, RER henceforth) which started operating during the second half of the 1970s. Like the train, the RER connects Paris to the suburbs, but for a shorter total distance of about 30 km. Most of the RER lines follow the train lines and were designed to improve the existing train network. An important distinction between the train and RER networks is that the latter has connections within Paris. This means the RER enables passengers to commute from one part of the Paris Metropolitan Area to another, going through Paris, but without having to switch to another train to cross the city. This represents a clear improvement to regional transit overall. As a whole, the RER network increased its number of lines from 1 to 5, its total length from 39 to 587 km, its number of stations from 22 to 243, and its number of municipalities with stations from 16 to 167 between 1975 and 2010.

In addition to these regional railroad networks, Paris is endowed with a very dense subway system (*métro* henceforth), which started in 1900, and is mainly connecting areas within Paris. Between 1968 and 2010, the métro network kept expanding, such that a few métro stations are now located beyond Paris, in the immediate outskirts of the CBD. The city of Paris and its closest suburban area (the first ring of municipalities out of Paris) also enjoy a tramway network. This fourth network is much more recent, dating back from the beginning of the 1990s, and is still expanding.

The companion work by Garcia-López, Hémet, and Viladecans-Marsal (2015*a*) provides a more thorough description of the transportation network in the Paris metropolitan area (including a description of the highway network and a table with the main characteristics of each network). Finally, it is important to note that the origins of these rail transit networks can be traced back to the 19th century. In Appendix A we show that there is a direct link between old and modern rails. In the empirical strategy of the following sections, we exploit this link using "historical" rail variables as instruments, that is, as sources of exogenous variations for our rail endogenous variables.

2.2 *Proximity to rail transit and local growth*

We can now turn to the main goal of this section: to assess the role played by rail transportation on the job decentralization process that we just identified, and on employment growth more generally. Using the 1968–2010 employment data and the location of railway stations for the 1,300 municipalities of the Paris metropolitan area, we therefore analyze the role of rail transportation on employment growth. To this aim, we estimate a growth function, focusing on the effects of proximity to railway stations by regressing the change in employment density on the distance between the center of the municipality and the nearest station:

$$\begin{aligned}\Delta_t \ln(\text{Employment density}) = \beta_0 &+ \beta_1 \times \ln(\text{distance to the nearest station})_{t-1} \\ &+ \beta_2 \times \ln(\text{densities})_{t-1} + \beta_3 \times \ln(\text{distance to CBD}) \\ &+ \sum_i (\beta_{4,i} \times \text{geography}_i) + \sum_i (\beta_{5,i} \times \text{history}_i) \\ &+ \sum_i (\beta_{6,i} \times \text{socioeconomy}_{i,t-1})\end{aligned} \quad (1)$$

We control for characteristics related to the initial urban spatial structure of metropolitan Paris such the distance to the CBD, and employment and population densities in year *t*-1). Also for municipal geography with altitude, index of terrain ruggedness, and elevation range variables. History variables are the population levels between 1962 and year *t*-2 and dummy variables for municipalities (1) that were Roman settlements (based on DARMC[3] maps), (2) that were major towns between the 10th and the 15th centuries (based on DARMC maps), and (3) between the 16th and the 19th centuries (based on Bairoch, 1988), and (4) with a monastery built between the 12th and 16th centuries (based on DARMC maps). Socioeconomic variables are computed for year *t*-1 and are the unemployment rate, the shares of employment in Manufacturing, in Construction, and in Services, the share of executives and professionals, and the share of population with university degree.

The estimated coefficients are displayed in Table 2. In columns 1 and 2, the results for the whole 1968–2010 period reveal that the further away a municipality was from a station, the more its employment density decreased over the period. To put it differently, these estimates reveal that proximity to rail stations fosters employment growth. Decomposing the total period into two subperiods (columns 3 and 4) shows that this concentration around transit is observable both at the beginning and at the end of the period, but is more marked in the early years of the period (1968 to 1990), corresponding to the first and main improvements of the railway network.

Evidence of the decentralization process described in the previous subsection is presented in columns 5 to 7, in which the regressions control for the interaction between the distance to the closest railway station and a dummy variable indicating the CBD. The coefficients for this interaction term reveal that conditional on belonging to the CBD (the 20 *arrondissements* of Paris), getting closer to rail station tends to reduce employment over time, a clear sign of job decentralization.

Finally, we can note that the estimated coefficients for proximity to rail stations remain stable when we control for the proximity to highway ramps, as reported in Appendix C. These regressions also show that the distance to the closest highway ramp does not relate to employment growth.

[3] The Digital Atlas of Roman and Medieval Civilizations (DARMC) is a website with free GIS maps for the Roman and medieval worlds (see `darmc.harvard.edu/icb/icb.do`).

Table 2: The effect of rail transit on employment growth and decentralization, TSLS estimates

Dependent variable:	Δln(Employment density)						
	40 year period		Subperiods		Decentralization?		
	1968–2010	1968–2010	1968–1990	1990–2010	1968–2010	1968–1990	1990–2010
	[1]	[2]	[3]	[4]	[5]	[6]	[7]
ln(Dist to station) in year *t-1*	-0.229[a]	-0.407[a]	-0.236[b]	-0.158[b]	-0.428[a]	-0.249[b]	-0.148[b]
	(0.050)	(0.134)	(0.118)	(0.067)	(0.133)	(0.119)	(0.065)
ln(Dist to station) in year *t-1* × CBD dummy					1.425[a]	0.900[b]	0.223[b]
					(0.429)	(0.352)	(0.130)
ln(Emp density) in year *t-1*		-0.678[a]	-0.513[a]	-0.368[a]	-0.646[a]	-0.492[a]	-0.368[a]
		(0.071)	(0.071)	(0.043)	(0.071)	(0.072)	(0.043)
ln(Pop density) in year *t-1*		0.504[a]	0.407[a]	0.349[a]	0.433[a]	0.360[a]	0.345[a]
		(0.106)	(0.098)	(0.054)	(0.106)	(0.103)	(0.055)
First-stage statistic	176.52	42.25	42.25	84.19	42.12	42.12	88.50
ln(Distance to CBD)	N	Y	Y	Y	Y	Y	Y
Geography	N	Y	Y	Y	Y	Y	Y
History	N	Y	Y	Y	Y	Y	Y
Socioeconomy	N	Y	Y	Y	Y	Y	Y
Instrument/s:	ln(Distance to the nearest 1870 railroad line)				ln(Dist to 1870 rail) ln(Dist 1870 rail) × CBD dummy		

Notes: 1300 observations in each regression. Robust standard errors are in parentheses. [a], [b], and [c] indicates significant at 1, 5, and 10 percent level, respectively.

3. Is Paris decentralization diffuse or clustered around subcenters?

After establishing that the Paris metropolitan area went through a job decentralization process related to the improvement of the railway transportation network, we now want to characterize the spatial pattern of this process: Does decentralization follow a *polycentric* spatial pattern, reinforcing existing secondary centers (subcenters) and/or fostering the emergence of new ones? Or does it rather reflect a *dispersed* spatial pattern, in which suburban land is occupied by low-density settlements? To answer these questions, we first identify subcenters for each census year between 1968 and 2010 before analyzing the evolution of employment inside these subcenters versus noncentral locations between 1968 and 2010.

3.1 Identifying and characterizing subcenters

An employment subcenter is a place with a significantly larger employment density than nearby locations that has a significant effect on the overall spatial distribution of jobs. We identify employment subcenters using the method first developed by McDonald and Prather (1994) and improved by McMillen (2001). The main idea is to estimate densities following a monocentric spatial pattern. The predicted densities obtained are subtracted from the corresponding real densities. From these residuals, those that are positive and statistically significant are selected.

While McDonald and Prather (1994) estimate by OLS a two dimensional density function (log of employment density on the distance to CBD, as in section 2.1), McMillen (2001) suggests estimating a three-dimensional density function (log of employment density on north-south and east-west distances to CBD) with a Locally Weighted Regression (LWR). Both improvements allow to take into account geographical differences, which, in terms of the spatial pattern of densities, can occur in any direction from the CBD (e.g. steeper density gradients on the north side than on the south side of the city). They additionally allow to define any type of monocentric spatial pattern: concave, convex or linear.

We therefore estimate the following employment density function:

$$\begin{aligned}\ln(\text{Employment density}) = \gamma_0 + \gamma_1 \times \text{north-south distance to CBD} \\ + \gamma_2 \times \text{east-west distance to CBD}\end{aligned} \tag{2}$$

where density is measured as jobs per hectare, and distances are in kilometers. The CBD is defined as the 20 *arrondissements* that make up the city of Paris. Distance to CBD is the distance to the centroid of the *4th arrondissement* (corresponding to the town-hall of Paris).

Since our estimates are based on LWR, we need to define a bandwidth. As McMillen (2001) points out, this is a critical choice because we need a monocentric benchmark. We experiment with alternative window sizes ranging from 1% to 9% and from 10% to 90% (see Table B.1 in Appendix B). After visual inspection, we find that the first monocentric spatial structure appears when the nearest 50% observations are included in each local regression. Interestingly, this is the value used by McMillen (2001) for some US cities. We also experimented with a selection rule based on the Akaike information criterion. However, the selected window size (7%) was clearly related to a polycentric spatial structure (see and compare Tables B.1 and B.2 in Appendix B).

Second, for each site we compute the residual as the difference between the log of real employment density and the estimated log of employment density. We then select those that are significantly positive, according to their own standard errors that can vary over space (McMillen, 2001). We use two critical thresholds, 1.96 and 1.64, that are associated with a 5% and a 10% significance level, respectively.

Finally, we group the selected sites in subcenters when they are contiguous. We use a "queen" criterion for contiguity: two sites (municipalities) are contiguous if they share at least one point in their boundaries. See McMillen (2001, 2003) and Garcia-López (2010) for further details on this procedure.

This methodology enables us to identify subcenters for each census year between 1968 and 2010, which are described in Table 3. For each year, we report two figures, respectively corresponding to subcenters identified using positive residuals significant at the 5% level and at the 10% level. From Panel A, we can see that the number of subcenters identified at the 5% level (respectively, at the 10% level) increased from 20 to 26 (respectively from 21 to 35) between 1968 and 2010. Panel B reveals that these subcenters hosted 1,756,000 jobs in 2010 (respectively 1,979,000), corresponding to an increase of about 600,000 jobs since 1968 (respectively 560,000). We can also observe that subcenters are heterogeneous in terms of size, with an increasing number of large subcenters (more than 20,000 jobs), in line with the decentralization process: in 1968, between 15% and 20% of subcenters hosted more than 20,000 jobs, contrasting with a range of 42% to 50% in 2010. Finally, we want to emphasize that the number of subcenters and the number of jobs in the subcenters do not differ much whether the subcenters are identified using positive residuals a the 5% level or at the 10% level. We will henceforth use the subcenters identified at the 10% level in our analysis.

Table 3: Employment subcenters in metropolitan Paris, 1968–2010

	1968		1975		1982		1990		1999		2010	
Resid. significant at:	5%	10%	5%	10%	5%	10%	5%	10%	5%	10%	5%	10%
Panel A: Number of subcenters												
All subcenters	20	21	26	27	30	32	29	34	31	34	26	35
$\geq$ 10,000 jobs	7	8	13	14	18	16	19	21	19	19	19	23
$\geq$ 20,000 jobs	3	4	8	7	9	12	13	13	13	12	13	15
Panel B: Jobs ('000) in subcenters												
All subcenters	1,152	1,419	1,319	1,667	1,237	1,665	1,373	1,788	1,441	1,782	1,756	1,979
$\geq$ 10,000 jobs	1,088	1,350	1,254	1,601	1,169	1,582	1,326	1,720	1,369	1,693	1,714	1,909
$\geq$ 20,000 jobs	1,022	1,290	1,184	1,501	1,040	1,513	1,252	1,618	1,281	1,602	1,624	1,788

Note: LWR estimates use a window size of 0.5 (i.e., the nearest of the 50% observations).

Table 4: Municipalities in employment subcenters in metropolitan Paris, 1968–2010

	1968	1975	1982	1990	1999	2010
Panel A: All subcenters						
All municipalities	88	97	93	95	95	89
Emerging as (part of) subcenters	–	18	7	11	12	5
Disappearing as (part of) subcenters	–	9	11	9	12	11
Always in subcenters	57	57	57	57	57	57
Panel B: Subcenters $\geq$ 10,000 jobs						
All municipalities	73	81	75	80	78	76
Always in subcenters	42	42	42	42	42	42
Panel C: Subcenters $\geq$ 20,000 jobs						
All municipalities	67	73	69	68	69	65
Always in subcenters	38	38	38	38	38	38

Note: Employment subcenters identified using McMillen (2001)'s method with a LWR window size of 50%, and for positive residuals significant at the 10% level.

Table 4 further describes the identified subcenters (at the 10% level) regarding the number of municipalities they encompass. We can first notice that the number of municipalities that form a subcenter of their own or that are part of a subcenter is quite stable, from 88 in 1968 to 89 in 2010, oscillating between 93 to 97 in the meantime. The last line of Panel A illustrates a certain stability in the composition of subcenters: among all the municipalities belonging to a subcenter, 57 are constantly identified as a subcenter (or as part of a subcenter) over time. The remaining municipalities may have emerged as part of a subcenter at some point, or, alternatively, stopped being considered as such.

3.2 The spatial pattern of decentralization

In order to determine the spatial pattern of employment decentralization, we now compare the evolution of employment inside and outside these subcenters over the period of interest.

Table 5 displays the number of jobs in each type of area (e.g. subcenter versus non-central) for all census years (columns 1 to 6), and the corresponding variation between 1968 and 2010 (column 7). In the *non-constant geography* panel (Panel A), the figures correspond to all subcenters and all non-central locations identified at a given date, some of them having appeared or disappeared as subcenters since the previous wave. In other words, the geography is not constant in the sense that the municipalities included in the *Subcenters* category (or, by symmetry, in the *Non-central* category) differ between two points in time. By contrast, the figures reported in the *constant geography* panel (Panel B) correspond to geographical zones that are fixed over time according to various criteria. Here, the geography is constant in the sense that the municipalities included in each type of zone considered are the same at each point in time. For instance, the *Always subcenters* category includes the 57 municipalities that are identified as a subcenters (or part of one) in all six years, while the *Always noncentral* group refers to municipalities that were not identified as (part of) a subcenter in *any* year. Similarly, the 35 municipalities identified as (part of) a subcenter in 2010 are included in the *Subcenters in 2010* group for all years, even if they may not have been (part of) a subcenter before 2010, while the remaining 1,265 municipalities go under the *Non-central in 2010* label. Finally, *1968 Non-central to subcenters* refers to municipalities that were non-central in 1968 and, at some point, became (part of) a subcenter and remained as such until 2010, while municipalities that were (part of) a subcenter in 1968 and, at some point, lost this status up to 2010 are labeled as 1968 *Subcenters to non-central*.

The figures reported in Table 5 reveal several interesting characteristics of the decentralization process. We can see from the non-constant geography panel (Panel A) that subcenters always concentrate around a third of all jobs in the Paris metropolitan area. Non-central municipalities represented around one fifth of all jobs in the metropolitan area in 1968, but up to one third in 2010 (while they include roughly 1,200 municipalities out of the 1,300 under study). Since the municipalities included in a given category vary from one year to another, it is however difficult to compare the employment shares at different dates and to appreciate the increase in employment share for non-central municipalities in this panel.

For this reason, we now turn to the figures of the constant geography panel (Panel B). We can first note that the number of jobs located in the 57 municipalities that are always identified as (part of) a subcenter has increased over time, from 1,028 thousands in 1968 to 1,372 thousands in 2010, which corresponds to a growth rate of 33.5% (column 7). The increase in the number of

Table 5: The spatial pattern of decentralized employment in metropolitan Paris, 1968–2010

	1968 [1]	1975 [2]	1982 [3]	1990 [4]	1999 [5]	2010 [6]	1968–2010 [7]
Panel A: Non-constant geography							
Subcenters	1,419	1,667	1,665	1,788	1,782	1,979	560 (39.5%)
MA share	33.2%	35.7%	35.4%	35.2%	35.3%	34.9%	
Non-central	992	1,090	1,232	1,472	1,659	1,893	901 (90.8%)
MA share	21.6%	23.3%	26.2%	29.1%	32.9%	33.4%	
Panel B: Constant geography							
Always subcenters	1,028	1,136	1,112	1,168	1,183	1,372	344 (33.5%)
Always non-central	754	880	961	1,136	1,260	1,383	629 (83.4%)
Subcenters in 2010 (not all years)	104	221	316	438	506	606	502 (482.7%)
1968 Non-central to subcenters	63	176	267	381	450	537	474 (752.4%)
Non-central in 2010 (not all years)	455	518	508	519	493	510	55 (12.1%)
1968 Subcenters to non-central	359	374	348	347	330	342	-17 (-4.7%)

Note: Employment values are thousands of jobs. Growth rates are in parentheses. Employment subcenters identified using McMillen (2001)'s method with a LWR window size of 50%, and for positive residuals significant at a 10% level.

jobs in *always non-central* municipalities is even more striking: this subset of municipalities saw its number of jobs grow by 83.4% over the period, with 629 thousands additional jobs. Although this increase in the number of jobs is almost twice as large as the one experienced by *always subcenters* municipalities, we must bear in mind that the latter represent less than 5% of municipalities.

We can also observe that the magnitude of employment growth in *2010 subcenters* and in *1968 noncentral to subcenters* is very large, both in absolute and relative terms.

4. Does rail transit cause subcenter formation?

After analyzing the job decentralization process in the Paris metropolitan area, we eventually turn to the most important part of this paper, where we contribute to the literature by establishing that rail transit causes subcenter formation. To answer to this key question, we proceed in two steps. We first investigate whether the existence of a rail station in a suburban municipality increases the probability that this municipality becomes (part of) a subcenter. Then, we examine whether proximity to rail stations also increases the likelihood of becoming (part of) a subcenter, even when the station is not built on the municipal ground.

In both steps, our empirical strategy consists in regressing the probability that a municipality becomes a subcenter on a *rail station variable*. In section 4.1, where we explore the role of the existence of a rail station, this variable indicates whether there is a station within the administrative boundaries of the municipality or the number of stations and lines in the municipality. Alternatively, in section 4.2, this variable measures the distance between a municipality and the closest station. All regressions include controls for the characteristics related to Paris urban spatial structure (geography, history, and socio-economic variables) that were used in Equation (1). The general equation, that will be estimated using probits, can thus be expressed as follows:

$$\begin{aligned}\text{Prob(subcenter)}_t = \beta_0 &+ \delta_1 \times \text{Rail station variable}_t \\ &+ \delta_2 \times \ln(\text{densities})_t + \delta_3 \times \ln(\text{distance to CBD}) \\ &+ \sum_i (\delta_{4,i} \times \text{geography}_i) + \sum_i (\delta_{5,i} \times \text{history}_i) \\ &+ \sum_i (\delta_{6,i} \times \text{socioeconomy}_{i,t})\end{aligned} \tag{3}$$

In order to correct for the potential biases related to the endogenous location of rail stations, we use instrumental variable estimates, relying on a historical instrument: a dummy variable indicating whether a given municipality was crossed by a rail (a train line) in 1870. Appendix A extensively documents how past transportation infrastructures shape modern ones, and discuss the validity of the 1870 rail network as an instrument for the location of current stations. A very close identification strategy is developed in our companion paper (Garcia-López *et al.*, 2015*a*), to which we refer for further details. However, the use of this instrument comes with a caveat: since we only have one instrument for several potentially endogenous variables (one for each year), we are left with no choice but to pool all observations together, irrespective of the year. As a consequence, we now include year fixed effects in our regressions.

4.1 Do rail stations lead to subcenters?

In order to establish whether the existence of a rail station in a suburban municipality increases the probability that this municipality becomes (part of) a subcenter, we estimate equation 3 using the subsample of the 1,280 suburban municipalities (excluding the 20 *arrondissements* of Paris).

The marginal effects of the corresponding (second-stage) results are displayed in Table 6. Columns 1 to 7 presents results estimated on the full subsample of all suburban municipalities. In columns 1 and 2, the station variable represents the number of lines times station, which counts the total number of lines having a stop in a municipality (it can be seen as a weighted count of the number of stations). The station variable then simply counts the number of stations in columns 3 and 4, and indicates the existence of a station in columns 5 to 7.[4] We will restrict our comments on the specifications that control for the geographical and historical characteristics, after noting that the marginal effects are significantly reduced in the conditional regressions.

Column 4 indicates that an additional station increases the probability that the municipality becomes (part of) a subcenter by 2.8%. This effect is exactly the same as that of having an additional line stopping in the municipality (column 2). This does not come as a surprise given that most of the suburban municipalities are only crossed by one train line, so that the number of lines-stations is actually very close to the number of stations.

Regarding the existence of a station, we estimate a slightly larger effect, around 4% over the whole period (column 6). This difference in magnitude can be interpreted as saying that *what matters the most in explaining subcenter formation is the mere existence of a train station, not the number*

[4]Therefore, if a municipality has two stations, with n_1 lines stopping in one station and n_2 lines in the other one, the "number of lines-stations" variable takes a value of $n_1 + n_2$, the "number of stations" variable takes a value of 2, and the dummy variable is equal to 1.

Table 6: The effect of rail stations on subcenter formation, IV Probit - Marginal effects

Dependent var.:	Probability of being (part of) a subcenter									
	All suburban municipalities							Without always subcenters		
Variable type:	Number of lines-stations		Number of stations		Dummy=1 for municipality with stat			Dummy=1 for municipality with stat		
Period/year:	68-10 [1]	68-10 [2]	68-10 [3]	68-10 [4]	68-10 [5]	68-10 [6]	75-10 [7]	75-10 [8]	1975 [9]	2010 [10]
Station variable	0.087^{a}	0.027^{b}	0.092^{a}	0.028^{b}	0.142^{a}	0.040^{c}	0.047^{c}	0.053^{b}	0.035^{c}	0.075^{c}
	(0.024)	(0.012)	(0.025)	(0.013)	(0.046)	(0.022)	(0.025)	(0.022)	(0.021)	(0.045)
F-S statistic	73.24	26.99	71.68	25.34	127.12	41.11	39.41	38.04	33.81	31.63
ln(Densities)	N	Y	N	Y	N	Y	Y	Y	Y	Y
ln(Dist to CBD)	N	Y	N	Y	N	Y	Y	Y	Y	Y
Geography	N	Y	N	Y	N	Y	Y	Y	Y	Y
History	N	Y	N	Y	N	Y	Y	Y	Y	Y
Socioeconomy	N	Y	N	Y	N	Y	Y	Y	Y	Y
Observations:	7680	7680	7680	7680	7680	7680	6400	6115	1223	1223
	(1280 suburban municipalities × 6 census years)						(1280×5)	(1223×5)		
Instrument:	Dummy=1 if municipality is crossed by a 1870 rail									

Notes: Regressions in columns 1 to 8 include year effects. Robust standard errors and are in parentheses (and are clustered by municipality in regressions in columns 1 to 8). ^{a}, ^{b}, and ^{c} indicates significant at 1, 5, and 10 percent level, respectively.

of stations. This effect increases to 4.7% when we focus on the 1975-2010 period (column 7), suggesting either that the effect is delayed in time, or that the transportation system built after 1975 (mostly the RER) explains a larger part of the overall effect.

In order to dig further into this time variation, we focus on the 1975-2010 period in columns 8 to 10, taking the municipalities systematically identified as subcenters out of the sample. The estimated effect over the period jumps to 5.3% (column 8) confirming the idea of an reinforced effect in the most recent period (the effect goes from 3.5% in 1975 to 7.5% in 2010 (columns 9 and 10), but the difference is not significant).

We also check that these estimates are robust to subcenter size and definition. The Table in Appendix D (Panel A) shows that the effect is always between 3.5% and 4.4%, whether we focus on municipalities of more or less than 50,000 inhabitants, and whether we rely on subcenters identified using the 5% criterion (instead of 10% in the main results).

We then refine our results by investigating the train station effect, looking alternatively at two different train types: suburban trains versus RER. The corresponding results are displayed in columns 1 to 4 of Table 7 for the former train type, and in columns 5 to 8 for the latter. Over the 1968-2010 period, we estimate that the presence of a suburban train station in a municipality increases the likelihood that it becomes a subcenter by 3.4% (column 2). As before, this effect slightly increases (to 3.9%) when we focus on the 1975-2010 period (column 3), and goes up to 4.4% once we exclude municipalities that are always identified as a subcenter (column 4). These figures are of the same order of magnitude, although slightly lower than the estimates obtained for all train types in the previous table (the corresponding figures being 4%, 4.7% and 5.3%

respectively).

On the other hand, the RER results reveal that this particular type of train has a much stronger impact on subcenter formation. The existence of a RER station is indeed found to increase the probability of becoming (part of) a subcenter by 14% over the 1968-2010 period (column 6), an effect about four times as large as the suburban trains'. Interestingly, looking at the later period (after 1975) does not show a significantly different effect (13.5%, column 7).

Table 7: The effect of train and RER stations on subcenter formation, IV Probit - Marginal effects

Dependent var.:	Probability of being (part of) a subcenter							
	Train stations				RER stations			
	All suburban municipalities			Without always sub	All suburban municipalities			Without always sub
Period:	68-10 [1]	68-10 [2]	75-10 [3]	75-10 [4]	68-10 [5]	68-10 [6]	75-10 [7]	75-10 [8]
Station dummy	0.175[a] (0.049)	0.034[c] (0.020)	0.039[c] (0.021)	0.044[a] (0.017)	0.680[a] (0.191)	0.140[a] (0.046)	0.135[a] (0.036)	0.102[a] (0.034)
F-S statistic	114.12	44.56	43.62	36.83	29.43	10.74	9.91	11.21
ln(Densities)	N	Y	Y	Y	N	Y	Y	Y
ln(Dist to CBD)	N	Y	Y	Y	N	Y	Y	Y
Geography	N	Y	Y	Y	N	Y	Y	Y
History	N	Y	Y	Y	N	Y	Y	Y
Socioeconomy	N	Y	Y	Y	N	Y	Y	Y
Observations:	7680	7680	6400	6115	7680	7680	6400	6115
	(1280 × 6 years)		(1280×5)	(1223×5)	(1280 × 6 years)		(1280×5)	(1223×5)
Instrument:	Dummy=1 if municipality is crossed by a 1870 rail							

Notes: All regressions include year effects. Robust standard errors are clustered by municipality and are in parentheses. [a], [b], and [c] indicates significant at 1, 5, and 10 percent level, respectively.

4.2 *Does proximity to rail stations lead to subcenters?*

We now want to examine the effect of the distance to a train station on subcenter formation. This presents a double advantage: it enables to measure the spatial effect of the presence of a train station, and allow to consider the effect of a train station on municipalities that are deprived of any. In other words, we investigate whether the effect of a rail station can go beyond the boundaries of the municipality where the station is located.

To this aim, we now use the distance (in log) of a municipality's centroid to the closest train station as the "train station variable". The main conclusion to be drawn from the results reported in Table 8 is that train stations have spatial effects: being closer the a station increases the probability to be (part of) a subcenter, even for municipalities without any station.

As in the previous section, we find a very similar effect of the proximity to any type of train or to suburban train alone. In this case, getting closer to a station by one kilometer increases the probability of becoming a subcenter by 2.4% (columns 2 and 6), or by 2.7% considering the 1975-2010 period (columns 3 and 7). On the other hand, the effect of being one kilometer closer to an RER station is estimated at 4.2% (column 10). Therefore, proximity to a station matters in the suburbanization process, especially for RER station.

We obtain similar results when we restrict our sample to the 977 suburban municipalities that do not have any station within their boundaries (columns 4, 8 and 11). This effect, of 3% for suburban trains and 4.9% for RER, confirms the spatially lagged effect of train stations. Finally, we also checked that our results are robust to subcenter size (more or less than 50,000 inhabitants) and definition (subcenters identified using the 5% threshold instead of 10%). These tests are reported in Appendix D (panel B of Table D.2).

Table 8: The effect of rail proximity on subcenter formation, IV Probit - Marginal effects

Dependent var.:	Probability of being (part of) a subcenter										
	All suburban stations				Train stations				RER stations		
	All suburban muni			Without muni-stat	All suburban muni			Without muni-stat	All muni		Without muni-stat
Period:	68-10	68-10	75-10	75-10	68-10	68-10	75-10	75-10	75-10	75-10	75-10
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]
ln(Distance)	-0.092^a	-0.024^a	-0.027^a	-0.027^a	-0.105^a	-0.024^a	-0.027^a	-0.030^b	-0.127^a	-0.042^b	-0.049^a
	(0.014)	(0.007)	(0.007)	(0.007)	(0.016)	(0.009)	(0.009)	(0.012)	(0.017)	(0.019)	(0.019)
F-S statistic	203.20	82.82	82.44	39.92	171.24	43.08	42.40	19.25	87.80	21.28	12.92
ln(Densities)	N	Y	Y	Y	N	Y	Y	Y	N	Y	Y
ln(Dist to CBD)	N	Y	Y	Y	N	Y	Y	Y	N	Y	Y
Geography	N	Y	Y	Y	N	Y	Y	Y	N	Y	Y
History	N	Y	Y	Y	N	Y	Y	Y	N	Y	Y
Socioeconomy	N	Y	Y	Y	N	Y	Y	Y	N	Y	Y
Observations:	7680	7680	6400	4885	7680	7680	6400	4885	6400	6400	4885
	(1280×6)		(1280×5)	(977×5)	(1280×6)		(1280×5)	(977×5)	(1280×5)		(977×5)
Instrument:	ln(Distance to the nearest 1870 rail)										

Notes: All regressions include year effects. Robust standard errors are clustered by municipality and are in parentheses. ^{a}, ^{b}, and ^{c} indicates significant at 1, 5, and 10 percent level, respectively.

To summarize the results of this section, two main points can be highlighted. First, train stations do play a role in the subcenter formation process, and this effect is spatially lagged: the existence of a train station increases the probability of becoming part of a subcenter by 4 to 5%, and decrease at a rate of about 3% per kilometer. Second, the RER is the type of train having the most important effect, with a direct effect of around 14% for municipalities with a station, and a spatial decay of about 5% per kilometer.

5. Conclusions

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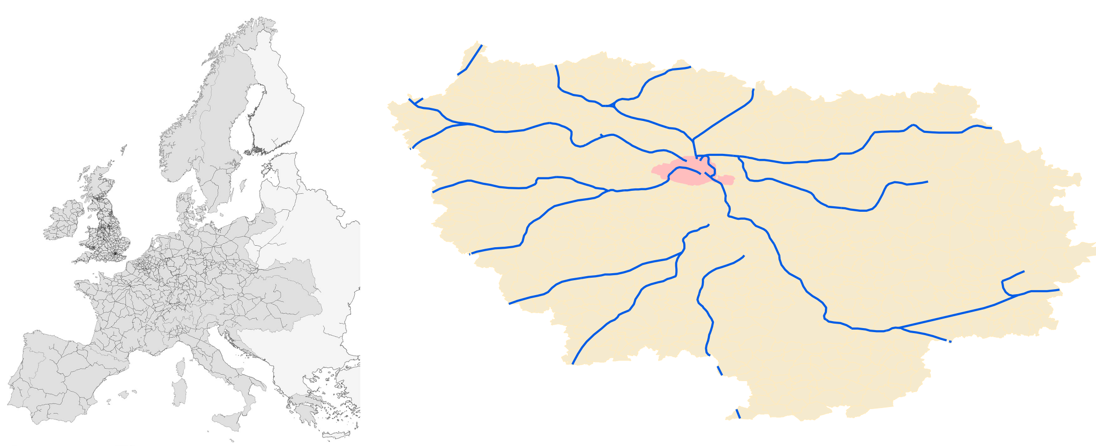
Appendix A. Rail transit in Paris: Past and present

One of the main purposes of this paper is to evaluate whether and to what extent transportation has fostered the emergence of employment subcenters in metropoliran Paris. However, first we need to deal with an identification issue because transportation and its improvements are not placed randomly. On the contrary, they are endogenous to employment and/or population location and growth. Planners may for instance decide to improve the connection of deprived areas in order to boost their economic activity or attract population. In order to address this issue, we adopt an instrumental variable approach in which some variables, named instruments, are used as sources of exogenous variation for our transportation endogenous variables.

Recent literature highlights the advantages in terms of exogeneity and relevance of using 'historical' and 'planned' instruments. For instance, Baum-Snow (2007), Michaels (2008) and Duranton and Turner (2012) use the 1947 plan of the interstate highway system as an instrument for modern highways in the US, and Duranton and Turner (2012) additionally rely on the 1898 railroad network. Garcia-López (2012) uses the ancient Roman roads, and the 19th century main road and railroad networks as instruments for highways and railroads in metropolitan Barcelona. Finally, Garcia-López *et al.* (2015*b*) use the ancient Roman roads and the 1760 Bourbon roads (post routes) to instrument current highways in Spain.

Following the above mentioned literature, we instrument modern railroads in metropolitan Paris with a historical instrument, the 1870 railroad network. The first French railroads were built at the beginning of the 19th century, but slightly later than in the UK due to Napoleon wars: the first line connecting Paris to a city located 18 km away (Saint-Germain) was not opened before 1837. In 1870, the railroad network was based on 698 km of railroad lines. Due to the high levels of centralization in France, it had a star-shaped form centered around Paris (Figure A.1).

Figure A.1: The 1870 railroads



Source: Own elaboration based on Martí-Henneberg (2013) maps.

Is the 1870 rail network a valid instrument?

As above mentioned, the fact that modern roads and railroads were built following ancient infrastructures has already been argued and used in the literature. Common sense would suggest that in France as well, past infrastructures shape current ones due to practical reasons: it is easier and cheaper to build new transportation infrastructures as an improvement of old ones for instance, or close to them (Duranton and Turner, 2012). We now test empirically the credibility of this assumption in the context of the metropolitan area of Paris. To do so, we conditially regress our endogenous rail variables on their historical counterparts and some control variables:

$$\begin{aligned}\text{2010 Rail transit variable} = \alpha_0 + \alpha_1 \times \text{1870 rail transit variable} \\ + \sum_i (\alpha_{2,i} \times \text{control variables})\end{aligned} \tag{A.1}$$

It is important to point out the importance of the control variables, in particular geography and history. Although ancient transportation infrastructures may be exogenous because of the length of time since they were built, the significant changes undergone by society and economy in the intervening years, and, in particular, because neither of them were built to anticipate employment and population changes in a distant future; it is also true that other factors such as the geography are likely to have influenced the construction and location of both ancient and modern transportation infrastructures for obvious reasons related to the feasibility and convenience of infrastructure building. From this point of view, it is crucial to include geographic characteristics such as altitude, index of terrain ruggedness, and elevation range as controls to comply with the exogeneity condition.

On the other hand, it is equally important to control for the historical context, since it may explain both the presence of former infrastructure and the economic importance of present-days municipalities. In order to fulfill the exclusion restriction, and because there are no historical employment and population data at the municipal level prior to 1962 and 1968, we control for history by including the population level in 1962 and dummy variables indicating (1) whether municipalities were Roman settlements, (2) whether they used to be major towns between the 10th and the 15th centuries and (3) between the 16th and the 19th centuries, and (4) whether they had a monastery built between the 12th and 16th centuries. These dummy variables come from the Digital Atlas of Roman and Medieval Civilizations, with the exception of the major cities of the 16th to 19th centuries which are identified in Bairoch (1988). To put it differently, we assume *conditional* exogeneity of the proposed instruments, as suggested by (Duranton and Turner, 2012).

Regarding the relevance of our potential instruments, Table A.1 shows results for versions of Eq. (A.1) in which we analyze the relationship between modern and past railroads in terms of the presence of stations and proximity to them. In particular, in Panel A, we study whether suburban municipalities crossed by a 1870 rail receive a rail stations. In all cases (pooled vs. cross section regressions in columns 1 and 2-3, all railroads vs. train and RER regressions in columns 1 and 4-5) we find significant and positive coefficients for the presence of 1870 rails. In Panel B, we estimate the effect of municipality proximity to 1870 rail on the municipality proximity to the nearest modern rail. Conditional on control variables, estimated coefficients for the 1870 distance variable are positive and highly significant. As a whole, results in Table A.1 clearly show that historical rails matter for modern rail construction and location.

Table A.1: Modern rail transit as a function of past rail transit, OLS estimates

Panel A: Rail stations						**Panel B:** Proximity to rail stations			
Dependent var.:	Dummy=1 if muni with station					Dependent var.:	ln(Dist to nearest station)		
Rail type:	Rail			Train	RER		Rail	Train	RER
Period/year:	75-10	1975	2010	75-10	75-10	Period:	75-10	75-10	75-10
	[1]	[2]	[3]	[4]	[5]		[6]	[7]	[8]
Dummy=1 if crossed	0.179^a	0.177^a	0.168^a	0.173^a	0.031^a	ln(Distance to	0.180^a	0.121^a	0.093^a
by 1870 rail	(0.029)	(0.030)	(0.030)	(0.028)	(0.009)	nearest 1870 rail)	(0.029)	(0.028)	(0.026)
Adjusted R^2	0.37	0.30	0.39	0.24	0.24	Adjusted R^2	0.54	0.42	0.71
F-S statistic	38.04	33.81	31.63	36.83	11.21	F-S statistic	39.92	19.25	12.92
ln(Densities)	Y	Y	Y	Y	Y	ln(Densities)	Y	Y	Y
ln(Dist to CBD)	Y	Y	Y	Y	Y	ln(Dist to CBD)	Y	Y	Y
Geography	Y	Y	Y	Y	Y	Geography	Y	Y	Y
History	Y	Y	Y	Y	Y	History	Y	Y	Y
Socioeconomy	Y	Y	Y	Y	Y	Socioeconomy	Y	Y	Y
Observations:	6115	1223	1223	6115	6115	Observations:	4885	4885	4885
	(1223×5)			(1223×5)			(977 muni × 5 years)		

Notes: Pooled regressions in Columns 1 and 4 to 8 include year effects. Cross section regressions in Columns 2 and 3 include a constant. Columns 1 to 3, Columns 4 and 5, and Columns 6 to 8 show first-stage results for regressions in Table 6 Columns 8 to 10, Table 7 Columns 4 and 8, and Table 8 Columns 4, 8 and 11, respectively. Robust standard errors are clustered by municipality and are in parentheses. ^{a}, ^{b}, and ^{c} indicates significant at 1, 5, and 10 percent level, respectively.

Appendix B. LWR and urban spatial structure in metropolitan Paris, 1968–2010

Table B.1: Employment spatial structure and LWR: A benchmark to identify subcenters

	1968	1975	1982	1990	1999	2010
1% LWR Benchmark	Polycentric	Polycentric	Polycentric	Polycentric	Polycentric	Polycentric
3% LWR Benchmark	Polycentric	Polycentric	Polycentric	Polycentric	Polycentric	Polycentric
5% LWR Benchmark	Polycentric	Polycentric	Polycentric	Polycentric	Polycentric	Polycentric
7% LWR Benchmark	Polycentric	Polycentric	Polycentric	Polycentric	Polycentric	Polycentric
9% LWR Benchmark	Polycentric	Polycentric	Polycentric	Polycentric	Polycentric	Polycentric
10% LWR Benchmark	Polycentric	Polycentric	Polycentric	Polycentric	Polycentric	Polycentric
30% LWR Benchmark	Polycentric	Polycentric	Polycentric	Polycentric	Polycentric	Polycentric
50% LWR Benchmark	Monocentric	Monocentric	Monocentric	Monocentric	Monocentric	Monocentric
70% LWR Benchmark	Monocentric	Monocentric	Monocentric	Monocentric	Monocentric	Monocentric
90% LWR Benchmark	Monocentric	Monocentric	Monocentric	Monocentric	Monocentric	Monocentric

Table B.2: Employment spatial structure and LWR: Akaike information criterion

	1968	1975	1982	1990	1999	2010
1% LWR Akaike inf. crit.	746	767	770	778	774	782
3% LWR Akaike inf. crit.	397	433	446	462	460	479
5% LWR Akaike inf. crit.	346	386	402	423	422	446
7% LWR Akaike inf. crit.	336	377	393	417	417	444
9% LWR Akaike inf. crit.	340	380	396	421	421	450
10% LWR Akaike inf. crit.	345	386	401	426	426	456
30% LWR Akaike inf. crit.	573	598	593	605	590	631
50% LWR Akaike inf. crit.	817	837	820	828	797	843
70% LWR Akaike inf. crit.	1081	1112	1094	1109	1067	1120
90% LWR Akaike inf. crit.	1284	1331	1318	1346	1301	1364

Appendix C. Do rails and highways jointly foster local growth in Paris?

Table C.1: The effect of rail transit and highways on employment growth, TSLS estimates

Dependent variable:	Δln(Employment density)		
Period:	1968–2010	1968–1990	1990–2010
	[1]	[2]	[3]
ln(Dist to rail station) in year *t-1*	-0.446[a]	-0.276[b]	-0.165[c]
	(0.123)	(0.110)	(0.089)
ln(Dist to highway ramp) in year *t-1*	-0.090	-0.092	-0.314
	(0.126)	(0.105)	(0.202)
ln(Emp density) in year *t-1*	-0.677[a]	-0.512[a]	-0.381[a]
	(0.071)	(0.071)	(0.041)
ln(Pop density) in year *t-1*	0.478[a]	0.380[a]	0.308[a]
	(0.101)	(0.094)	(0.066)
First-stage statistic	58.00	58.00	53.19
ln(Distance to CBD)	Y	Y	Y
Geography	Y	Y	Y
History	Y	Y	Y
Socioeconomy	Y	Y	Y
Instruments:	ln(Distance to the nearest 1870 railroad line)		
	ln(Distance to the nearest Roman road)		

Notes: 1300 observations in each regression. Robust standard errors are in parentheses. [a], [b], and [c] indicates significant at 1, 5, and 10 percent level, respectively.

Appendix D. Does rail transit cause subcenter formation? Robustness checks

Table D.1: The effect of rail on subcenter formation, IV Probit - Marginal effects: Robustness to subcenter size and significance

Panel A: The effect of rail stations					**Panel B:** The effect of proximity to rail stations				
Dependent var.:	Probability of being subcenter				Dependent var.:	Probability of being subcenter			
	Subcenter jobs		5% residuals			Subcenter jobs		5% residuals	
	≥50,000	<50,000	All obs	Without alw-sub		≥50,000	<50,000	All obs	Without alw-sub
Period:	75-10	75-10	75-10	75-10	Period:	75-10	75-10	75-10	75-10
	[1]	[2]	[3]	[4]		[5]	[6]	[7]	[8]
Station dummy	0.036^{c}	0.039^{c}	0.035^{c}	0.044^{b}	ln(Distance)	-0.015^{a}	-0.017^{a}	-0.013^{c}	-0.011^{c}
	(0.020)	(0.023)	(0.021)	(0.021)		(0.005)	(0.006)	(0.008)	(0.006)
F-S statistic	34.20	42.76	38.95	38.29	F-S statistic	81.35	80.63	80.41	84.55
ln(Densities)	Y	Y	Y	Y	ln(Densities)	Y	Y	Y	Y
ln(Dist to CBD)	Y	Y	Y	Y	ln(Dist to CBD)	Y	Y	Y	Y
Geography	Y	Y	Y	Y	Geography	Y	Y	Y	Y
History	Y	Y	Y	Y	History	Y	Y	Y	Y
Socioeconomy	Y	Y	Y	Y	Socioeconomy	Y	Y	Y	Y
Observations:	6214	6117	6400	6195	Observations:	6214	6117	6400	6195
Instrument:	Dummy=1 if crossed by a 1870 rail				Instrument:	ln(Dist to the nearest 1870 rail)			

Notes: All regressions include year effects. Robust standard errors are clustered by municipality and are in parentheses. ^{a}, ^{b}, and ^{c} indicates significant at 1, 5, and 10 percent level, respectively.

Table D.2: The effect of rail on subcenter formation, IV Probit - Marginal effects: Robustness to identification strategy

Panel A: The effect of rail stations

Dependent var.:	Probability of being subcenter			
	No historic towns		No 1870 stations	
	All obs.	Without alw-sub	All obs	Without alw-sub
Period:	75-10	75-10	75-10	75-10
	[1]	[2]	[3]	[4]
Station dummy	0.067^{a}	0.046^{b}	0.049^{b}	0.037^{c}
	(0.023)	(0.022)	(0.023)	(0.021)
F-S statistic	34.55	35.13	8.53	10.64
ln(Densities)	Y	Y	Y	Y
ln(Dist to CBD)	Y	Y	Y	Y
Geography	Y	Y	Y	Y
Lagged pop	Y	Y	Y	Y
Socioeconomy	Y	Y	Y	Y
Observations:	6185	5955	5385	5245
Instrument:	Dummy=1 if crossed by a 1870 rail			

Panel B: The effect of proximity to rail stations

Dependent var.:	Probability of being subcenter			
	No historic towns		No 1870 lines	
	Without mun-stat	Without alw-sub	Without mun-stat	Without alw-sub
Period:	75-10	75-10	75-10	75-10
	[5]	[6]	[7]	[8]
ln(Distance)	-0.023^{a}	-0.010^{c}	-0.025^{a}	-0.020^{a}
	(0.006)	(0.005)	(0.004)	(0.004)
F-S statistic	52.85	50.69	95.90	90.45
ln(Densities)	Y	Y	Y	Y
ln(Dist to CBD)	Y	Y	Y	Y
Geography	Y	Y	Y	Y
Lagged pop	Y	Y	Y	Y
Socioeconomy	Y	Y	Y	Y
Observations:	4780	4675	4110	3945
Instrument:	ln(Dist to the nearest 1870 rail)			

Notes: All regressions include year effects. Robust standard errors are clustered by municipality and are in parentheses. ^{a}, ^{b}, and ^{c} indicates significant at 1, 5, and 10 percent level, respectively.

Results in Columns 1 to 4 are robustness checks to specifications in Table 6 Columns 7 and 8. Results in Columns 5 to 8 are robustness checks to specifications in Table 8 Column 4. These robustness checks are based on dropping observations/municipalities related to the 1870 railroad network (in some cases, we drop almost 1,000 observations):

- Columns [1] and [5] → Since the 1870 railroad network was probably planned to serve the most important municipalities during the 19th centuries, we first drop municipalities were important. We do not have population data at the municipality level for these years, as a result we use our historical dummy variables that signal the most important towns through history. That is, we drop municipalities that were Roman settlements and/or major towns during the 10th and 19th centuries and/or with monastery built between the 12th and 16th centuries.
- Columns [2] and [6] → Above + I also drop the 57 (× 4 years) municipalities that are always identified as (part of) subcenters.
- Columns [3] and [7] → I drop municipalities with railroad stations built before 1870 and crossed by the 1870 railroad lines, respectively.
- Columns [4] and [8] → Above + I also drop the 57 (× 4 years) municipalities that are always identified as (part of) subcenters.

In general, results hold: coefficients remain significant and with the roughly the same magnitude. Instruments are still valid, with high First-Stage F-Statistics (Columns 1-2 and 5 to 8) or with values close to 10 (Columns 3 an 4).

The comments corresponding to this appendix still need to be included in the main text