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Two metropolisation gradients in the European system of cities revealed by scaling laws

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Abstract

Urban systems share with other complex systems constraints on their dynamics that are revealed by pervasive structural features, among which scaling laws. Scaling laws are relationships between cities' attributes and their size (here measured by their population). When the relationship is non proportional with exponents larger than 1, scaling laws indicate the relative concentration of some urban functions at the higher levels of urban hierarchies. Superlinear scaling thus reveals the metropolisation trends that are produced in the urban system, according to our evolutionary theory perspective, by the hierarchical diffusion of innovation waves. Considering the current urban changes linked with the globalisation processes as an 'innovation' that is likely to diffuse hierarchically in urban systems, we analyse the relationships between 25 indicators expressive of their position in globalisation processes and the size of European cities (356 largest functional urban areas of the 28 European Union member states plus Switzerland and Norway). When summarised in a single metropolisation factor, we expected to find a unique superlinear scaling relationship that would reveal the hierarchical structure of the unifying European system of cities. We instead identify two distinct metropolisation gradients for each of the Western and Eastern subsystem that we interpret according to the delayed globalisation process in the latter. This provides a demonstration of the usefulness of scaling laws for summarising stages in the process of hierarchical diffusion of innovation in systems of cities.

Keywords

European cities, urban systems, metropolisation, urban hierarchy, scaling laws

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Introduction

Because cities are connected through a multiplicity of relationships, they self-organise in 'systems of cities' (Berry, 1964) Most often, the structure of such systems has been described within the limits of national boundaries (for instance in the series of publications of the IGU Commission on urban geography, as Bourne et al., 1984, or Ostendorf et al., 1997). The connections between cities accelerate the general process of diffusing all kind of innovations that are the driving forces transforming the features of urban economic functions and urban life of their inhabitants. As a consequence, cities belonging to a system of cities become more and more interdependent and co-evolve. Evidence of co-evolution of cities within systems of cities has been brought up within the frame of national territories, as for instance in the French case by Pumain and Saint-Julien (1984) and by Paulus (2004). Many attempts have been made for extending such investigations towards larger subsets of well-connected cities crossing the national borders, identifying for instance 'global cities' entering in a world-wide competition (Jensen-Butler et al. 1997; Sassen, 1991, 2007; Taylor, 2001) or regional subsets of cities that are narrowly connected by networks of multinational firms (Rozenblat et al., 2017), through very dense air flight connections or information and power networks (Smith and Timberlake, 1995).

All European cities seem to be currently involved in multiple connections that integrate Europe in 'global systems' (Derudder et al., 2003; Taylor, 2001). This globalisation trend may intensify a generic evolutionary process called 'metropolisation' that tends to increase inequalities among cities in national and transnational urban systems and reinforces their hierarchical structure over time (Bretagnolle et al., 2000; Pumain and Moriconi-Ebrard, 1997). Metropolisation is a term used in urban geography for coining the concentration of attributes associated with the highest levels of urban functions in large cities. Activities of higher centrality and highly skilled occupations (as for instance 'creative classes') are overrepresented in the largest cities of a system of cities. This generates scaling exponents larger than 1 when these attributes are correlated with city size. According to an evolutionary theory of urban systems (Pumain, 2006), it is assumed that each large innovation wave, because of its mainly hierarchical diffusion process, contributed to differentiate quantitatively and qualitatively cities at the higher levels of urban hierarchies, which became 'metropolises'. The recent metropolisation process that is linked with the globalisation trends can be defined as the concentration in a few cities of the nodes of the main long-distance networks that integrate cities in economic, social and cultural globalisation. As a result, these few cities host most global functions and become metropolises that are larger and more diversified than less important cities in the same system.

We assume that the contemporary globalisation processes that have intensified in the last few decades can be interpreted as an 'innovation wave' that cities are both generating and adapting to. Innovation waves in a broad sense encompass all kind of productive and societal changes that accompany major inflexions in the history of a society (Lane et al., 2009). According to the evolutionary theory of urban systems (Pumain, 2006), innovations waves are the driving force that triggers urban growth and change. Innovations follow a more or less hierarchical diffusion process in urban systems and generate in cross-sectional observations a variety of non-linear relationships between city sizes and the distribution of urban functions. Usually, functions of the most recent wave scale superlinearly with city size (relative over-concentration in largest cities), while those of the previous waves are simply proportional to the population, and oldest ones scale sublinearly (meaning a relative over-concentration in smallest towns). Thus, conversely, these 'scaling laws' can be used for identifying the processes that are specific of a recent innovation wave (Pumain et al., 2006), here the globalisation trend.

In this paper, we evaluate to what extent the globalisation process affects cities of different sizes and regions in Europe, by analysing the distributions of socio-economic functions of cities in a variety of networks expressive of globalisation trends. We assume that European metropolises can be individualised through their concentration of the networking functions according to their specialisation (high level, rarity) and diversity (variety of urban activities) (Hall and Pain, 2006). Our study differs from other works that try to isolate only a few urban functions that would reveal a participation in global networks. For instance P. Taylor and the Globalization and World Cities Research Network (GAWC) (Taylor, 2001, 2014), Sassen (2009) or Kearney (2010) focused on the presence of multinational companies, especially in advanced service sectors, that would be characteristic of the cutting-edge economic sectors of the time We try to avoid a strict a priori selection of possible indicators of globalisation. We use scaling relationships for detecting among a diversity of potentially relevant international functions those that are significant of that process by concentrating more than proportional amounts of some activities in the largest cities. In a second step, we use multivariate analysis for constructing a synthetic view of the relative positions of European cities in this rich universe of metropolitan indicators.

This study relies on a large sample that includes the 356 largest European cities (from the 28 member states of European Union to which are added the states of Switzerland and Norway that are embedded through many connections within the urban networks of that territorial entity). Cities are defined according to a comprehensive delineation of functional urban areas (FUAs). First, we recall the main attempts that were made for ranking European cities according to a hierarchy in a diversity of urban functions, and we explain how superlinear scaling can help in identifying indicators that are more specific of metropolitan processes (Identifying metropolisation trends in a system of cities using scaling laws section); second, we discuss the difficulty of producing comparable urban indicators in Europe and which are now available for best revealing the participation of cities in global networks (Developing a data base for observing metropolisation levels among European cities section); third we identify which subset of variables may be expressive of contemporary metropolisation trends because of their superlinear scaling and we integrate the performances of cities on these relevant indicators through a multivariate analysis that summarises them in a general metropolisation index (Using scaling laws for building a metropolisation index in the European urban system section); comparing the position of each city on that index with its expected position according to its size leads to identifying two different regional trends in the European globalisation process (Advances and delays in the globalisation process section).

Identifying metropolisation trends in a system of cities using scaling laws

From many repeated systematic analyses by geographers, historians and economists, the progressive genesis of a coherent European system of cities in the last several centuries is rather well documented. The resulting structure of the system of cities including the hierarchy of sizes and diversity of urban functions has been described many times at that territorial level. We explain how scaling laws can help in providing efficient tools for summarising the hierarchical distribution of urban equalities that can be interpreted as reflecting the effects of innovation diffusion within urban systems.

Early emergence of a European system of cities

The first studies including a large set of European cities were focused on city development and spread in a specific region (Dickinson, 1967; Hall and Hay, 1980; Juillard and Nonn, 1976;

Meuriot, 1897). Further analyses began to consider European cities as part of a system. These studies were initially produced by historians such as Braudel (1966), De Vries (1984) and Bairoch et al. (1988), who assumed that the roots of the contemporary European system could be found in the shift from the Mediterranean system to Atlantic routes that began in the 16th century. The Industrial Revolution subsequently created a general growth of cities, favouring major cities as well as a surge of specialised manufacturing centres (Bretagnolle et al., 2000; Hohenberg and Lees, 1995; Pinol, 2003). Pumain and Moriconi-Ebrard (1997) has interpreted such observations within the framework of an evolutionary theory of urban systems, where cities adapt to the changes they create in a continuous way, following a general hierarchical process of innovation diffusion (Hägerstrand, 1952). This hierarchical process may be occasionally perturbed by more selective innovation waves that specialise subset of cities for some of their other comparative advantages that are independent of city size. On the whole, and besides the possible emergence of 'generations' of such specialised cities, the successive innovation waves that are firstly adopted by the largest cities lead to a growing inequality of city sizes in systems of co-evolving cities over time.

Can we provide a quantified evidence of such processes for the contemporary evolution of the European urban system? In the historical studies, it is usually the similarities in urban population growth rates and the demographic trajectories that are considered together with the observation of established exchanges and communication linkages for identifying co-evolving cities and comforting the hypothesis of emerging enlarged systems of cities. However, and especially during the last decades in Europe, the temporal delays in demographic and urban transitions between the Northern, Southern and Eastern parts of Europe (Cattan et al., 1999) have blurred the possible relationship between population growth and economic growth (Champion, 1989; Cheshire et al., 1989; Hall and Hay, 1980). Hall and Hay (1980), testing the wave diffusion of urban centres decline in Europe, highlighted some very uneven stages of urban development, revealing the strength of the national context over cities evolution. More recently, Turok and Mykhnenko (2007) identified a difference between Eastern and Western cities' population trajectories between 1960 and 2005, where national contexts seem weaker, but however they did not interpret the general trends in terms of wave diffusion. The economic functions that foster urban success and attractiveness and that characterise the metropolisation of the period have changed in a qualitative way more and more rapidly. Accordingly, indicators must be adapted but strict comparisons in time are not easy (Kresl and Singh, 2012; Van den Berg et al. 2001). That is why we suggest adopting a new method using scaling relationships for both selecting relevant indicators and measuring the stage of metropolisation processes in urban systems.

Scaling relationships and metropolisation in evolving urban systems

Metropolisation means a relative concentration of some urban functions in the largest cities of an urban system. That concentration implies that there is not a simple relationship of proportionality between the corresponding indicators and the population. To identify the shape of relationships between an urban indicator j whose value Xij is measured on a city i and cities population size Pi we use a power law

$$Xij \sim Pi^{\beta}$$

where the value of the β exponent is 1 if the relationship is simply proportional, above 1 if there is a systematic concentration of j in the largest cities of the system and below 1 if there

is a relative concentration of j in the smallest towns. This power law is called a *scaling law* as it describes how the indicator j varies according to scale throughout the system.

In the biological sciences, scaling laws obtained by adjusting power laws to the relationship between metabolism rates and the size of animal species are interpreted as revealing physical constraints on the development of living species during the biological evolution (West et al., 1999). The relationships between metabolism and species size are always sub-linear (β exponent below 1), meaning that processes similar to economies of scale have been realised during the biological evolution through the way energy is distributed into organisms, using fractal networks. The interpretation is not fully transposable to social sciences because innovation that triggers socio-economic and cultural evolution through the social exchange of information is distributed differently in space and time than matter and energy in the physical realm. Information flows do not follow the same rules as physical exchanges and, contrary to physical exchanges, may generate super-linear scaling laws (Bettencourt et al., 2007, Lane et al., 2009). Bettencourt and Lobo (2016) recently found such superlinear relationships for gross domestic product (GDP) or patents in 8 to 24 largest cities in five European countries. Indeed many case studies demonstrate a high variability in the values that are estimated for the scaling exponent of different urban features (Pumain et al., 2006), and at various urban scales (Arcaute et al., 2012). According to Pumain et al. (2006), there is a correlation between the values of β exponents for urban activities and their stage in the corresponding product cycle or innovation wave. The interpretation of ß values is as follows:

- $\beta > 1$: Leading technologies or activities (growing curve of current innovation cycle);
- $\beta \approx 1$: Commonplace (or banal) technologies and activities (stage of diffusion);
- $\beta < 1$: Mature functions (decay or substitution stage).

Therefore, measuring scaling relationships in cities may provide some indication of the stages of urban activities in innovation cycles that are reflected in their distribution among cities according to their size (Pumain, 2012). Scaling relationships thus directly translate the systemic constraints that weigh heavily on the fate of a city because of its membership in a system of cities. They reveal the power of exchange networks that connect cities and render their development interdependent. Scaling relationships when measured at a given date capture the degree of concentration of urban functions that is attained at a moment of their diffusion in the cities' system. Enumerating and summarising indicators that scale super-linearly with city size is thus a way of measuring the intensity of a metropolisation process within a system of cities that may be more pronounced at the start of a large innovation wave and less strong once the diffusion has occurred. Conversely it is possible to use the exponent of the power laws relating the functions and size of cities as a proxy for indicating the stage of the corresponding activities in the innovation wave, whatever the actual qualitative description of these urban indicators at different periods of time (Pumain et al., 2006).

Developing a data base for observing metropolisation levels among European cities

All studies trying to compare European cities report about three major limitations that hamper the quality of statistical comparisons: the lack of a common definition of a "city" in Europe; the lack of comparable indicators at the urban level among different countries; and the difficulty of measuring changes over time.

Regarding the first problem, comparative studies of the demographic evolution and economic profiles of European cities encounter difficulties because the spatial expansion of cities since the 1970s requires a revision of the delineations of urban entities (Van den Berg et al., 1982) Initial comparable measurements were made according to the spatial expansion of built-up areas to define urban agglomerations (Moriconi-Ebrard, 1994). In a second step during the 1990s, FUAs were defined based on commuters' mobility. Data are still missing for the rigorous, comparative implementation of this method (ESPON, 2006; Guérois and Pumain, 2008; Pumain et al., 1992; Rozenblat and Cicille, 2003), but good proxies are now available for the delineation of FUAs throughout Europe (BBSR, 2011; European Spatial Planning Observatory Network (ESPON), 2010; Guérois et al., 2012; Halbert et al., 2012)

The data limitation remains an acute problem. Eastern countries still suffer from a lack of data at a fine resolution level (ESPON, 2010), and Europe's enlargement from 15 to 28 countries increased this difficulty. The non-homogeneity of national nomenclatures hampers comparisons, especially for data involving unemployment and employment by activity sectors or professions (Cattan et al., 1999; Pumain and Saint-Julien, 1996). Occasionally, data about performance are only available at higher territorial levels and must be allocated to the urban areas in which most are concentrated (in most cases, NUTS3 are chosen as proxies for qualifying urban areas, for instance in ESPON, 2010 or in Hájková and Hajek, 2014). Meanwhile, it remains even more difficult to provide clear testing of urban processes, as the metropolisation trend, because we lack of consistent comparable data over long enough periods of time.

We participated in a collective effort for overcoming these difficulties (see Appendix 1 below and online supplementary material Appendix 2). Our sample of cities includes all 356 FUAs with more than 200,000 inhabitants in Europe 30 (European Union [EU] plus Switzerland and Norway). All indicators in this study were first collected at municipal level (GDP excepted, at NUTS3), and we aggregated their locations within FUAs all over Europe (Halbert et al., 2012). The threshold of 200,000 inhabitants was chosen because of previous empirical evidence showing that below this size, there was no opportunity to observe a complete metropolis in terms of diversity of functions and participation in multinational networks (Cattan et al., 1999; Rozenblat and Cicille, 2003; Rozenblat and Pumain, 2007). This database includes six complementary aspects of urban development that are considered essential for composing a metropolitan profile in the recent studies of European cities (BBSR, 2011; Halbert et al., 2012):

- The *Regional economic context* describes the size and the profile of the production according to GDP per activities. Some industrial or even agricultural relative specializations remain visible among Eastern European cities, contrasting with cities in central regions that transformed radically their economy toward the high technologies and advanced services.
- The *accessibility of cities* for air, railway or maritime transport is measured by the number of other cities accessible in a one day round trip; besides, air and maritime *attractiveness* is measured by the effective traffics, respectively of passengers and of containers.
- The *centrality in economy* is measured according to the position of cities in financial networks of the 3000 first multinational firms of the world (ranked by their turn-over) ORBIS-IGD (BvD/Bureau van Dijk, 2010) This database contains more than 1 million linkages of financial ownership between 800,000 enterprises. A first indicator measures the number of subsidiaries *controlled* by the headquarters located in each Functional Urban Area. A second indicator is the *attractiveness for foreign enterprises* measured by the

number of branches of foreign origin located in the FUA (Alderson and Beckfield, 2004). The number of international fairs reveals some '*temporary centrality*' contributing to the reputation of the city (fashion in Paris, Milan; cars in Stuttgart; art in Basel) (Torre, 2008).
- The *cultural attractiveness* is measured by the number of international congresses, tourist attractions (according to Michelin Europe), hotel nights and fashion shops.
- The *situation in the European research space* is measured by the number of students in universities and the number of financial supports received from the 6th framework programs (total number and number of those specialised in the 'converging' technologies of Nano, Bio-Technologies, Information and Communication (NBIC). Beyond the excellence of research, the indexes reveal the capacity of the research communities to attract support from EU.
- The *accessibility to European and International institutions* (measured by the number of them located in the FUA) *and number of lobbyists*, indicate the capacity of local institutions to support their enterprises and citizens to reach and get information at European and international level.

At first, 75 indicators were collected (the exact sources are indicated in online supplementary material Appendix 1). After removing redundancies, 25 variables remained that are listed in Table 1. They represent a first compromise between theoretical requirements for defining metropolisation processes and the available comparable data.

Using scaling laws for building a metropolisation index in the European urban system

We adjusted regression lines on the relationships between these 25 variables and city size in order to reveal which variables are best suited for detecting metropolitan effects. The urban functions that they describe when they scale super-linearly are systematically overrepresented in the largest cities and underrepresented in smaller towns, potentially corresponding to the most innovative aspects of urban functions revealing a participation in global networks. That is why we build thereafter a composite index from this selection of variables for ranking cities according to their relative position in the globalisation process.

Scaling exponents of urban attributes

The method consists of estimating on a log–log plot the β exponent of a power law expressing the amount of an urban function according to its population size:

$$\log \mathrm{URB\_FUNCTION} = \alpha + \beta \log \mathrm{POP}$$

where URB_FUNCTION is the urban function; POP is the population of FUAs; α is a constant corresponding to the hypothetical minimal quantity of log (URB_FUNCTION); β is the exponent of the power function between urban function and population.

Although the examples in Figure 1 show rather large variations in the European set of cities, translated into low or medium values for R^2, they are statistically significant and represent two opposite behaviours of urban functions according to city size. The value of the β index is below 1 for the number of cultural places (touristic attractions) (Figure 1(a)), meaning that this function is less than proportional to the size of the cities. Hosting places of touristic interest as well as international congresses are urban functions that are widely

Table 1. Scaling law exponents for 25 variables describing the European cities.

Theme	Label ($\beta > 1$, $\beta < 1$)	Variable	β	R^2	No. of cities
Regional economic context	GDP	GDP (in PPPs) 2006	1.12	0.85	356
	GDP_PRIM	Added value in primary sector	**0.50**	**0.23**	**356**
	GDP_EQUIP	Added value in equipment industry and construction	1.06	0.61	356
	GDP_CONSU	Added value in consumption industry	1.04	0.66	356
	GDP_TRADE	Added value in trade	1.19	0.76	356
	GDP_ADV_SERV	Added value in advanced services	1.27	0.63	356
	GDP_COLL_SERV	Added value in collective services	1.12	0.61	356
Accessibility and attractiveness	**ACCESS**	Number of possible destinations in one-day trip (accessibility)	**0.56**	**0.23**	**197**
	AIRPASS	Air passengers 2008	1.86	0.48	211
	PORT_SEA	Port traffic of goods in 2009 (in tons)	**0.61**		**156**
Economic centrality	**HEADQUART**	Multinational headquarters 2010	**0.93**	**0.50**	**130**
	FINANCE	Index of financial place 2008	1.30	0.52	254
	INTERSUB	Foreign subsidiaries in 2010	1.33	0.66	315
	CONTROL	Index of control of subsidiaries (controlled subsidiaries divided by located subsidiaries controlled by external firms of the FUA)	**0.08**		**315**
	FAIRS	Fairs and exhibitions	**0.67**	**0.28**	**90**
Cultural attractiveness	**CONGRESS**	International congresses (1999–2008)	**0.58**	**0.29**	**111**
	TOURISM	Number of touristic attractions	**0.69**	**0.26**	**309**
	FASHION	International brands of fashion and luxury	1.08	0.51	277
	HOTEL	Number of hotel nights	1.02	0.47	347
Situation in research space	FP6_FIN	Evaluation of FP6 financial support (investment in million euros)	1.55	0.44	350
	FP6_NBIC	Participation in NBIC FP6 projects	1.22	0.46	258
	STUDENTS	Number of students	**0.99**	**0.47**	**352**
Access to European institutions	**EUR_ORG**	European and international institutions	**0.33**	**0.09**	**67**
	INFO_CENT	Information and documentation centres of EU	**0.36**	**0.32**	**258**
	LOBBY	Number of EU lobbyists	**0.92**	**0.46**	**248**

FUA: functional urban area; NBIC: Nano, Bio-Technologies, Information and Communication; PPP: Purchasing Power Partly.
R^2 not significant: $p(t) > 1\%$
Note: The last column is the number of cities for which values are not zero. Cities with zero values are excluded from the estimation of scaling parameters but later included in the multivariate analysis.
Underlined text is β index higher than 1 and Bold text is for other values.

diffused in the European urban system, and more specialised cities are often relatively small towns that are attractive because of their location or their cultural heritage. In contrast, the total amount of financial support attributed from FP6 projects scales with a ß coefficient higher than 1 (Figure 1(b)). Here, the process involving research collaboration appears much

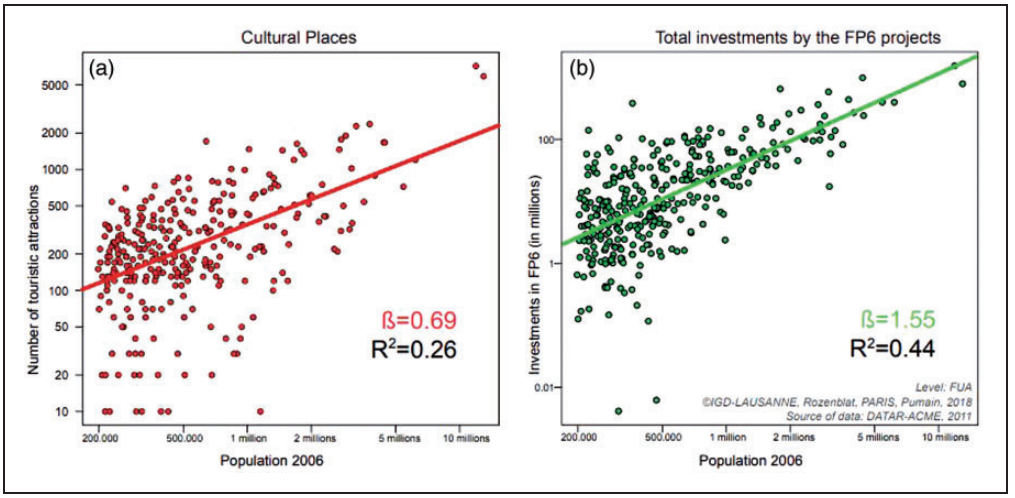


Figure 1. Scaling laws of European cities for two metropolitan functions.

more often in research centres located in large cities that concentrate this innovative urban function. The values of the β coefficient have been computed in the same way for all variables (Table 1).

All variables admitting a β index higher than 1 have underlined text in Table 1, and the others have bold text. The variables scaling super-linearly are the GDP (measured by added values) for nearly all economic sectors, numbers of air passengers, finance and foreign subsidiaries, international fashion and luxury brands, hotel nights, FP6 financial support and participation in FP6 for NBIC projects. These functions participate in the metropolisation process. Urban Product (GDP) is a good summary of this accumulation. The higher added values (especially in finance) are concentrated in a few large metropolises in Europe, corresponding to the location of investors, which are often multinational firms close to the higher performing research centres where all of the amenities of cosmopolitan life are present: hotels, fashion and luxury and accessibility to airports around the world.

In contrast, a few variables (sometimes at first sight surprisingly) scale sub-linearly and thus do not indicate a particular propensity to advantage the largest cities, seeming to escape the general metropolisation process whereas they are obviously part of it. We list these variables and suggest in parenthesis the most plausible explanatory factor for each of them, although this would deserve deeper investigation: the general accessibility index (the measurement of which may be influenced by geometrical location in Europe independently of city size); the size of ports' traffics (this activity is dependent of physical geography and not necessarily present in all large metropolises); the number of top headquarters of the 3000 first companies of the world central metropolises (this variable has a peculiar statistical distribution because London and Paris concentrate more than two-thirds of the headquarters and this urban function is present at least by one unit in 130 FUAs only); the index measuring the degree of control over subsidiaries (that index is a ratio between out- and in- control, thus small cities hosting the headquarters of a large company can control numerous companies in other cities (as Vevey in Switzerland), and at the opposite, large metropolises hosting many controlling companies, often as well attract many subsidiaries); the number of congresses (it is known from previous studies that cities receiving scientific or corporate meetings are chosen on the basis of their other amenities as

much as for their capacity in size); the attractiveness for tourists (touristic amenities are depending on physical landscapes or cultural heritage that are not always associated with large city size); the number of students (specialised university centers are sometimes located in smaller towns, Oxford, Cambridge or Heidelberg are famous examples); and the access to European institutions (including Brussels or Geneva, that are not among the largest metropolis, as the champions),. The headquarters, the index of control on subsidiaries, and universities (number of students), which are generally considered as metropolitan characteristics (Van Winden et al., 2007), are actually more widely diffused in the European urban system than some other functions.

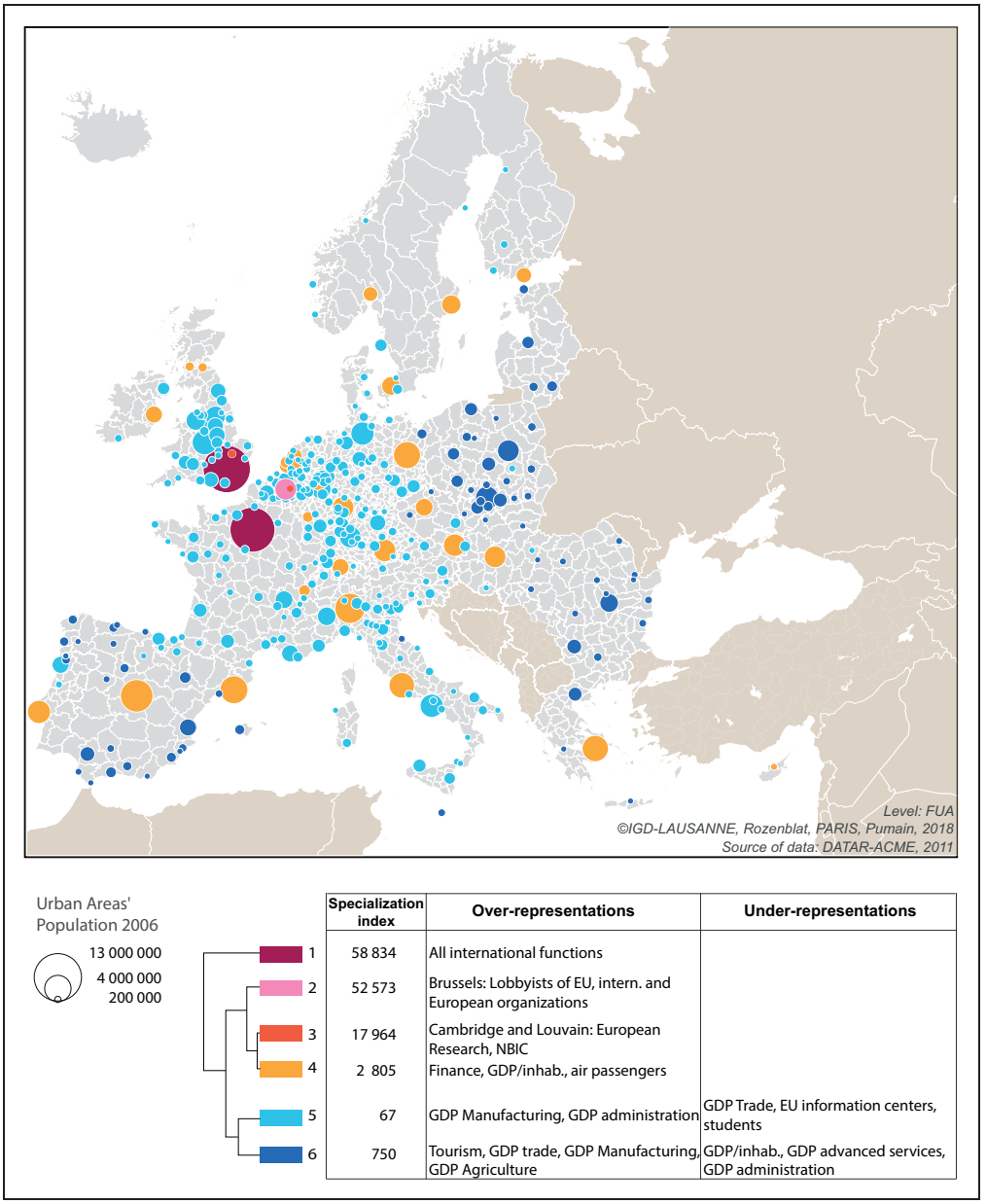
Building a composite metropolisation index

In order to get a synthetic measurement of metropolisation of urban activities as a tool for comparing the FUAs, we use a multivariate analysis. Many tests were made for taking into account the weights of cities without overemphasising this 'size effect' in the results, avoiding redundancies and taking care of the lognormal character of most statistical distributions. We decided that the 13 variables that scale super-linearly with city size had to be normalised by urban population, while the other could be expressed in absolute numbers. We checked that the results of the principal components analysis (PCA) are robust enough and not too sensitive to the way of measuring the variables for obtaining them (see online supplementary material Figure 1).

The PCA reveals a strong structure with two thirds of the total variance on the first two axes. The first axis (47%) summarises the number of congresses, tourist attractions, headquarters, students or the accessibility index, as well as other variables measured in relative terms: GDP/inhab. (especially GDP in advanced services/inhab.), air passengers/inhab. and brands of fashion and luxury/inhab (online supplementary material Figure 1(a)). The association of these functions isolates from the rest of the sample several of the largest European metropolises, such as Paris, London, Brussels, Amsterdam, Vienna and Madrid (online supplementary material Figure 1(b)). The largest Eastern European cities are positioned much lower along this axis, with Budapest, Prague and Warsaw having the highest scores among them.

While this first axis may be interpreted as a global index of metropolisation revealing the hierarchy of cities in this process, the second axis (17%) outlines a few high specialisations in specific metropolitan functions (or in less innovative ones) that are characteristic of small specialised cities: higher GDP/inhab. and, especially in advanced services, research, high-technology industries and the control index in multinational firms characterise the specialisation of cities as Cambridge, Leuven and Edinburg in one or several of these fields. At the opposite side are cities of the European Eastern and Southern periphery (Bucharest, Constanta and Heraclius) where trade and consumption dominate the economy.

A cluster analysis of all urban profiles according to the 25 variables was made using an ascending hierarchical classification software (with euclidian distance and maximising interclass variance), which generates six classes (no differences are observed when clustering operates on factors of the PCA). In Figure 2, the classification tree recalls the similarities between classes that are also qualified by a 'specialisation index' (distance between the average profile of the class and the mean urban profile), by the list of variables that are significantly over- or under-represented in their profile and coloured as the corresponding cities on the map: in blue for the less metropolised cities, orange and brown for medium categories and pink and red for the most metropolised. The map in Figure 2 clearly illustrates the prominent position of the two European capitals, Paris and



	Specialization index	Over-representations	Under-representations
1	58 834	All international functions	
2	52 573	Brussels: Lobbyists of EU, intern. and European organizations	
3	17 964	Cambridge and Louvain: European Research, NBIC	
4	2 805	Finance, GDP/inhab., air passengers	
5	67	GDP Manufacturing, GDP administration	GDP Trade, EU information centers, students
6	750	Tourism, GDP trade, GDP Manufacturing, GDP Agriculture	GDP/inhab., GDP advanced services, GDP administration

Figure 2. Metropolisation profiles of European Functional urban areas.

London, as well as the high level of metropolisation for most of the other capitals of European countries characterised by high-income levels, concentrating financial activities and attracting many air passengers, whereas Brussels has a more atypical role. But what is also very apparent in Figure 2 is the isolation of cities of Eastern Europe, whatever their size, in a single class also including smaller towns of the periphery (in Spain, Portugal and Greece) and whose profile denotes specialisation in less advanced economic sectors.

Advances and delays in the globalisation process

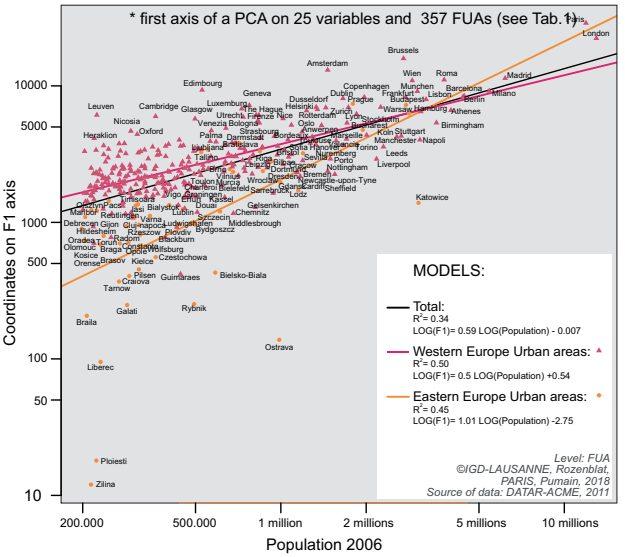
We have specified above in the Abstract and in the Introduction section of this paper that the metropolisation is a recurrent process in the history of urban systems that occurs each time an important wave of innovation hits the system. The actual stage of metropolisation in Europe is mainly linked with the globalisation of economy, which may appear as the 'innovation' of the recent decades. Global flows connecting urban economies were much less important in previous large innovation waves (as for instance during the first industrial revolution of 19th century or even during the wave accompanying the diffusion of automobile and electronics just after the second world war). The increase of communications and the financiarisation of the economy enable the building of global networks crossing national boundaries and connecting cities of different continents all over the world. The widening of global trade since the 1960s impacted at first the largest metropolises in Western Europe and as a consequence the hierarchy of city sizes became more contrasted (Bretagnolle et al., 2000; Hall and Hay, 1980; Rozenblat C and Pumain D., 1993). Because of the socialist regimes governing countries of Eastern Europe the openness to these post-war global processes was delayed there until the 1990s. Thus we can observe a quasi experimental situation about the possible impact of a political boundary including state regulation on the hierarchical diffusion process of an innovation.

Because it summarises the positively correlated variables describing the current metropolisation processes that are linked to or amplified by globalisation, the first axis of the PCA can be understood as ordering the cities along a gradient of globalisation, from the most involved cities in the process (Paris and London) to the less involved smaller towns. To measure the extent to which the level of globalisation of European cities, as measured by this gradient, is explained by their size, we adjusted a regression line between the coordinates of the 356 cities on the first axis of the PCA (log) and their population size (log) (Figure 3). This means implementing a general scaling relationship, with F1 as a variable representing a synthetic proxy of metropolisation index. As we noticed before that there may be inequalities between cities of the Western and Eastern part of Europe, we also repeated the adjustments after dividing the sample in two subsets (304 cities in Western part and 52 in Eastern part).

The model is relevant for the entire set of European cities ($R^2 = 0.34$), demonstrating that population size of cities is still a significant first proxy for assessing their relative positions in global networks (Figure 3(a)). But if we discriminate two groups of cities (Western and Eastern Europe), we obtain better qualities of adjustment ($R^2 = 0.50$ and $R^2 = 0.45$, respectively). There are indeed *two different gradients ordering two hierarchies of cities* according to their level of metropolisation. In Western Europe, the metropolitan level is less differentiated according to city size (the exponent of the power function is 0.5), indicating a relative but pervasive diffusion of globalisation processes in the smaller cities. In Eastern Europe, cities are still more differentiated according to their size (the exponent is 1.01), indicating a higher concentration of metropolitan features in the largest cities. The two models can be interpreted as corresponding to *two different stages of integration in the globalisation process* that are observable in the two parts of Europe: the first started mainly after the second world war on the Western side, the second since the 1990s only in the Eastern part.

One might be surprised that for the whole set of cities and for Western cities the scaling relationship between metropolisation index and population size has a value below 1, and one should not pay too much attention to the value of exponents in this particular scaling exercise, since for building our composite metropolisation index we have already normalised many variables in dividing them by urban population size in order to reduce the ranges of variation. It is more significant to come back to original variables and to compare the exponents of scaling relationships adjusted on each subset of cities

A- Coordinates of European Urban Areas on a metropolization factor according to their population (LOG-LOG)



B- Difference between the observed coordinate on F1 axis and the one estimated after the Urban Areas' population

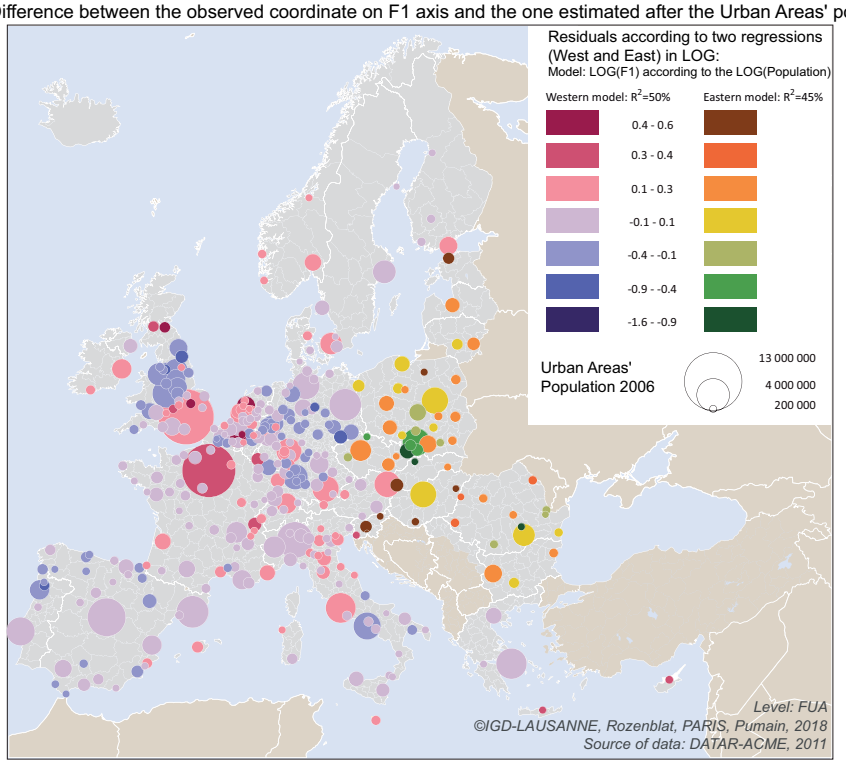


Figure 3. Advances and delays in the globalisation process: cities of the old and new member states.

(online supplementary material Table 1). What is striking there is that for all 13 original variables scaling superlinearly with city size, exponents have always higher values when measured on cities of Eastern Europe only. In other words, each indicator of a specific dimension in the European metropolisation process is much more differentiated according to city size in Eastern Europe than on the Western side and gives more advantage to the largest cities in this newly integrated region. Only the accompanying activities of luxury products and fashion are not (not yet?) as highly concentrated in large metropolises in cities of Eastern Europe, (explaining that would require a deeper investigation) whereas in the case of the number of students it is well known that education has been more evenly distributed in the urban system during the socialist period.

Using each model as a standard for positioning cities in the metropolisation process seems in any case a better solution than a crude comparison made on the whole set of European cities. We have computed the residuals of the regression of the scores on the PCA's first axis on population size according to each separate regression model for Western and Eastern cities. The method is tentative and may be seen as oversimplifying a complex process. In Figure 3(b), we have mapped these residuals figuring advances and delays of each city in this globalisation process as computed, all things being equal, with regard to their size and situation in Western or Eastern Europe. A spatial pattern appears in Western Europe, with a centre-periphery configuration (with some particularly low scores in the Iberian Peninsula and in the South of Italia), whereas advances and delays are not so clearly spatially distributed among cities of the Eastern part (see online supplementary material 'Appendix 2: Detailed comments on map of Figure 3').

Conclusion

We specified the globalisation trend in European cities by comparing 25 urban functions revealing the relative position of each of 356 FUAs in a variety of global networks. Different functions, according to their stage of diffusion in the European urban system have different abilities to hierarchise cities, while concentrating in the largest ones. We estimated scaling exponents in order to identify activities that are preferentially located in largest cities, as revealed by exponents of power laws explaining their importance by the population size of the city. The functions introducing strongest super-linear relationships are air transportation, finance and foreign subsidiaries and FP6 supports. At the opposite, the number of headquarters of multinational companies and the number of students in universities, which are generally considered as metropolitan characteristics, are already more widely diffused in the European urban system.

We assume that a variety of globalisation processes integrating European cities in multiple networks can be analysed as an 'innovation wave' that diffuse hierarchically in urban systems. The metropolisation trend that is induced by this hierarchical diffusion has been summarised by a factor of multivariate analysis that represents the relative position of European cities in this trend. Indeed this factor depicts a first view of the intensity of penetration of global networks among the whole European urban system. The relationship of its composing variables with city size as measured by population is often represented by super-linear scaling relationships that demonstrate a greater ability of the largest cities to capture the benefits of the innovation. However, a further examination enables in a second step to distinguish two different stages in the process according to the location of cities in the Western or Eastern part of Europe. Thus we managed to underline a major differentiation between the Western and Eastern European urban trends that had not yet been detected at that level.

The major result of our approach is in identifying two gradients of metropolisation that differentiate the participation of cities to global networks, according to the length of the presence of countries in the post-socialist economy and within the European Union. These two distinct relationships thus describe a two-stage process. In the Western part, which was open to global trends earlier, these trends have percolated deeper within the system of cities, whereas in the Eastern part, global processes are still specific to the largest cities. This evolution is paradoxical since in Eastern Europe the systems of cities inherited from the communist period were less hierarchised than in the Western part (Moriconi-Ebrard, 1994). This finding confirms the hierarchical character of the diffusion of any 'innovation wave' in a system of cities – as represented by the recent globalisation. Moreover, globalisation at this stage is not only delayed but has more differentiating hierarchical effects in Eastern Europe than in the Western part.

Thus, this static observation of urban hierarchies can somehow be interpreted in dynamic terms. What is happening in new member states is neither a replication with a delay nor a simple diffusion of the globalisation processes from the Western part; Rather, it reveals a different ability to catch up depending on the structure of national urban systems, and on the location of cities. Whether this difference will continue or whether it is only transitory is not certain, but in both cases, it would contribute to fostering spatial cohesion and to maintaining the functional diversity of the European urban system. European urban policies could consider the two trends we identify to provide better-adapted support while encouraging diffusion between cities and leveraging the adaptive properties of cities.

Appendix 1. Sources of indicators

This paper makes a secondary use of a database on European metropoles that was collected for another purpose thanks to a funding of the French DATAR and coordinated by Ludovic Halbert in 2011. We acknowledge for preparing the data reported in Table 1 the work of following partners:

- The regional economic context: built by the IGEAT – Free University of Brussels team (Christian Vandermotten), it takes into account the regional GDP per economic sector (NUTS3) (which is impossible to build at a strictly urban scale because of the lack of data at the municipality level);
- The accessibility and attractiveness of cities in terms of general accessibility by air and train (Alain L'Hostis from LVMT-IFSTTAR team in Lille) and air and port transport (built by UNIL Lausanne team for air and by Cesar Ducruet for ports [Géographie-Cités, Paris]);
- Economic centrality (based on the multinational firm network studies developed in UNIL Lausanne by C. Rozenblat and completed by P. Cicille (UMR ESPACE Montpellier, France) for fairs and exhibitions);
- Cultural attractiveness: includes congresses (Union of International Associations), tourist attractions (source: Michelin Europe), hotel nights (P. Cicille [UMR ESPACE Montpellier, France]), and fashion shops (C. Rozenblat [UNIL Lausanne] and IGEAT- Free University of Brussels B. Wayens);
- Situation in research space: general cooperation in FP6 by UNIL Lausanne C. Rozenblat and cooperation in NBIC sectors by M-N. Comin (Géographie-Cités, Paris); students in universities listed by P. Cicille (UMR ESPACE Montpellier, France);
- Access to European institutions: European and international institutions, Information and documentation centre of EU, number of EU lobbyists estimated by P. Cicille (UMR ESPACE Montpellier, France).

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