Urban Scaling of Knowledge Production: Diverging Trends in Scientific Research and Innovation Across European Cities (1980–2010)

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Research and innovation are complex activities which require deep division of knowledge and usually require cooperation of many people with narrow and complementary expertise (Balland et al. 2020). Scientific production and innovation are mostly urban phenomenon (Audretsch and Feldman, 1996, Glaeser et al. 1992) as it requires local interactions (Bettencourt et al. 2007) and it is conditioned by the existence of institutions (firms and universities) and concentration of human capital. Complex system research suggests that the magnitude of urban innovative output is the function of population size characterized by the "*urban scaling law*" (Bettencourt, Lobo, Helbing et al. 2007, Bettencourt, 2013). The larger the population, the more diverse factors we find in the city (Gomez, Lievano 2016), which in turn results in more frequent recombination.

Most of the research is using patents as output indicator of research and innovation (Bettencourt at al. 2007, Bettencourt and Lobo 2016, Balland et al. 2020). Empirical results show that large cities produce significantly more scientific output than their population predicts, and their beta scaling coefficient ranges from 1.26 (Balland et al. 2020) to 1.29 (Bettencourt et al. 2007) in the US. Research by Bettencourt and Lobo (2016) on selected four European countries showed that the coefficient is lower, where the aggregate coefficient for 4 European countries has a value of 1.13 and it differs significantly between countries. Fewer studies have analyzed scientific production through scientific papers (Nomaler et al. 2014, Balland et al. 2020). Nomaler et al. (2014) tracked the number of publications in Scopus for the period 1996–2008 in metropolitan and micropolitan statistical areas in the US. Their estimated coefficient of elasticity β was 1.78 and Balland et al. (2020) estimated the size of the β coefficient as 1,54. Estimation of scaling coefficient for the number of scientific publications in Europe is, to our knowledge, missing.

The aim of this paper is to answer question how does the scaling law characterise the evolution of the production of patents and scientific papers across cities in Europe. To achieve this, we use geocoded data on patents from De Rassenfosse, at al. (2019) and data of scientific papers of European universities from Scopus. We also use functional urban areas (FUA) (Dijkstra et al., 2019) as a spatial unit representing a city in Europe. Functional urban area comprises here densely inhabited cities and their surrounding areas (commuting zones) such that they constitute an integrated labor market. We estimated the population of cities from population density grids of the Center for International Earth Science Information Network (CIESIN, 2021). The final dataset consists of population, patents and academic papers of 631 cities from 31 European countries covering time period during 1980 - 2010.

Urban scaling law is a simple relation between population and output of cities, which is in our case number of scientific papers and number of patents:

$$Y(N,t) = Y_0(t)N(t)^{\beta}e^{\xi(t)}$$

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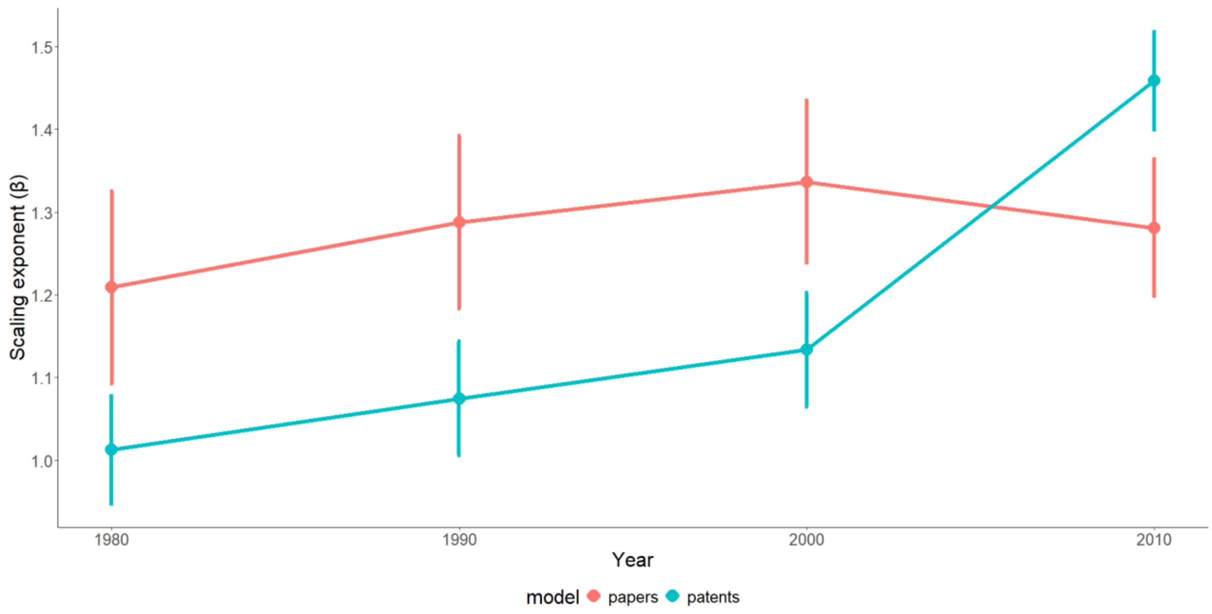
$Y(N,t)$ – city output (patents, papers)
$N(t)$ – population at time t
$Y_0(t)$ – baseline constant, function of time capturing European wide development/decline
β - scaling exponent (elasticity), $\beta > 1$ superlinear scaling, $\beta < 1$ sublinear scaling
$\xi(t)$ – statistical fluctuation

Our main interest is a size of scaling exponent β which expresses the average non-linear effect of population on the output. In other words, it represents the average elasticity between population and research and innovation output. Coefficient higher that 1 implies that larger cities are on average more productive than smaller ones. We use following simple OLS model to estimate the scaling exponent, in which *i* represent different cities in Europe:

$$lnY_i = lnY_0 + \beta lnN_i + \xi_i$$

The main goal of this analysis is to estimate the scaling exponent of European cities in the period from 1980 to 2010. The main results are presented in the graph below. We found that the scaling exponent of European cities for the production of academic articles was 1.21 in 1980, then increased slightly until 2000 when it reached 1.34, and then declined to 1.28 in 2010. Large cities, on average, have a higher production of scientific articles than their size would predict. The scaling exponent for patents has grown significantly over time. In 1980, it was 1.01 and substantially lower than the exponent for publications, but by 2010, it had risen above 1.42. This suggests that innovation (measured by patents) has become increasingly concentrated in large cities over time, while scientific production has remained more evenly distributed.



These divergent trends in recent years may result from multiple processes. First, large cities in Europe are building stronger innovation ecosystems and benefiting from local collaboration among firms, universities, and research centres, as well as from the concentration of human capital, investors, and supporting institutions. On the other hand, research funding in Europe has expanded beyond major academic centres, and thanks to cohesion policies, universities in smaller cities and peripheral regions have gained access to resources. The development of online collaboration, increased travel opportunities within Europe, and open access to scientific articles and research data have facilitated research in smaller cities. Compared to commercial innovation processes, scientific research is becoming less dependent on physical proximity and can increasingly be conducted remotely.

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