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Continuous vs. Discrete Urban Ranks: Explaining the Evolution in the Italian Urban Hierarchy over Five Decades

ECONOMIC GEOGRAPHY

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abstract

The reasons for changes in ranking within urban systems are a matter of a wide and long debate. Some focus on a continuous and smooth ordering of cities by their size within the urban system, in the tradition of Zipf's law. Others focus on discrete, discontinuous ordering, as cities take on functions at different levels, such as specialized market places or high-level education, in the tradition of Christaller. We enter the debate by empirically evaluating whether the same determinants explain continuous or discrete changes in urban ranks in the evolution of the Italian urban hierarchy over the years 1971 to 2011. We empirically show that small, continuous changes of cities' ranks have different drivers than large, discontinuous leaps. The presence of high-level functions in a city predicts major leaps across discrete ranks. Results are robust to the use of an instrumental variable strategy based on a shift–share argument.

Key words:
central place theory
agglomeration economies
high-level functions
functional upgrading

JEL codes:
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R11
R12

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The role of urban systems in explaining regional dynamics is debated in both the academic and policy arena, especially during the 2007–2008 economic crisis in which large cities have been interpreted as sources of resilience for regional economies. The mechanisms of urban systems' dynamics elicited a long-standing debate, where special emphasis is given to the idea that efficient urban systems foster balanced growth while also enhancing equity, competitiveness, and sustainability.[1]

As they focused on the growth performance of individual cities, empirical studies after the crisis overlooked the consequences of city change within the urban system. As a result, the implications of urban development of one city surpassing another in terms of rank are often ignored. Yet, a long tradition of literature inspired by Christaller's Central Place Theory (1933) argues that rank changes in the urban hierarchy only occur with a change in urban functions (e.g., a regional market center or host of size-intensive activities like universities; Eeckhout 2004; Parr 2017). In this article, we posit that cities' embedding in the spatial urban system allows growth, for instance, through long-distance cooperation with other cities (Ma et al. 2014), borrowed size from nearby cities (Alonso 1973), and borrowed functions from nearby cities (Camagni, Capello, and Caragliu 2016). Thus, this article studies the importance of functional specialization, as well as borrowed size and functions, and long-distance cooperation in rank changes of cities within a national urban system.

This article innovates with respect to a literature characterized by conflicting views of urban system development. The clash lies in whether rank is a continuous measure of city size with constant (log) differences between ranks (as in the celebrated rank-size rule; Zipf 1949) or a chunkier measure in which groups of cities that perform similar functions in the urban system have comparable sizes (Christaller 1933). In the case of continuous rank measures, urban growth stems from a random process yielding a continuum of urban populations and thereby

[1]Un bon réseau urbain hiérarchisé peut contribuer à favoriser un dévéloppement régional équilibré [a good hierachical urban network can contribute to favoring a balanced regional development] (Beguin, 1988, 242), authors' translation.

indistinguishable differences in the roles they play (Gabaix 1999). In the latter interpretation, following Christaller (1933), rank-size changes are large between groups of similar cities but small within those groups.

This distinction has important ramifications. The interpretation of cities' sizes as a continuous distribution suggests that cities grow for random or generic reasons, obeying statistical regularities. By contrast, the second interpretation implies that large modifications in the urban hierarchy only come as a result of structural changes, the inclusion of new functions hosted, and a new role in the national division of labor.

The empirical regularity first proposed in Zipf (1949) crowds out explanations that, at least initially, stemmed from a geographic approach. However, the views underlying Zipf's law and the Christallerian approach have actually been shown to be compatible with each other. The seminal example of mutual compatibility occurs in a multipurpose shopping model in which consumers group purchases in order to minimize transport costs (Eaton and Lipsey 1982), thus causing a demand externality that generates clustering processes. While it is analytically difficult to identify an optimal agglomeration pattern, subsequent works (in particular Quinzii and Thisse 1990) show when the equilibrium outcome is socially optimal, that is, when different types of commodities exhibit a different range.

In this article, we present an empirical horse race between these two approaches. In fact, changes in the hierarchies depicted by the Christaller approach can be seen as nested in a Zipf model, where leaps upward (or downward) are discrete and allow cities to reach for higher clusters (ranks), characterized by superior functions.

In order to illustrate our findings, we proceed as follows. The next section presents the theoretical debate on rank definition and change, discussing the different views on the continuity or lumpiness of urban ranks, and recalling the theories suggesting the determinants of urban growth that will be applied in the empirical analysis. The methodology used to identify discrete urban ranks is in the section that follows. This is followed by a section that illustrates the empirical specification, describing our data. The penultimate section presents the empirical results on the characteristics of the cities changing their relative position. Moreover, the section also features results of the determinants of changes across both continuous and discrete urban ranks, along with a subsection dealing with identification issues. The final section concludes.

Structure and Determinants of Evolution of Urban Hierarchies

Continuous or Discrete Ranks?

A vast literature studies the nature of urban ranks, focusing on whether they should be considered as discrete or continuous. The common starting point is that cities are seen as complex systems growing on the basis of a bottom-up process. Once agglomeration economies justify the emergence of at least a concentrated settlement in an economically coherent area, urban growth processes step in "to facilitate a division of labor that generates scale economies, and it is a simple consequence of competition and limits on resources that there are far fewer large cities than small" (Batty 2008, 769).

However, cities are not all the same. Larger cities perform different activities than smaller ones. Larger cities typically attract top-tier functions such as diplomatic sees, large theaters and entertainment venues, control branches of major multinational corporations, etc. In the 1930s, the way these activities would be performed by cities belonging to different layers of the urban system was described by Christaller (1933) and Lösch (1940) as obeying a hierarchical distribution with cities of increasingly higher rank performing activities proper to their own rank plus all activities typical of lower ranks. This approach is now labeled Central Place Theory.

After WWII, when the work by Christaller and Lösch was translated into English, a lively debate emerged on the statistical properties characterizing the spatial distribution of cities and their role within urban systems. How this debate evolved over time in the economic geography field proper is excellently discussed in Barnes (2012). Zipf (1949) and Simon (1955) represent milestones of this debate, eventually leading to the emergence of the field of econophysics.

Zipf's (1949) law is among the most striking empirical regularities in modern economies: it describes a log-linear relationship between the log size of cities and their ranks within an urban system. The law states that the log of city rank is a function of the log of city size, with a slope equal to -1 (Gabaix 1999). This regularity is traditionally rationalized on the basis of Simon's (1955) random growth model, which suggests that two statistical distributions—negative binomial and log series—represent the stationary solutions of several stochastic processes, including (among other economic phenomena) urban population levels.

The random growth framework offers specific predictions on an economy's urban system: (1) within each urban system, cities organize along an urban hierarchy characterized by a continuum of functions played by each city with constant distances between cities of different ranks along the urban hierarchy; and (2) any equilibrium distribution population remains fairly constant over time, with little chance for cities to reposition in rank distributions unless extraordinarily fast urban growth takes place.

Proponents of a continuous size distribution in the urban hierarchy argue that an urban model that fails to meet the predictions of Zipf's and Gibrat's law (Ioannides and Overman 2003) lacks interpretative power in measure that is not theoretically justifiable. The pervasive diffusion of power and scaling laws in urban economics is documented in Gabaix (2016) and testified to by the way several theoretical contributions strive to document each model's adherence to this condition (Behrens, Duranton, and Robert-Nicoud 2014).

A general, if not universal, consensus gradually crystallized around the idea that long-run equilibrium cities organize along a regular array of dimensions (i.e., discrete ranks). The identification of power laws is hampered by the substantial variance occurring in the tails of the distribution, that is, areas of an urban system that comprise both small and large cities (Clauset, Shalizi, and Newman 2009). Stylized facts suggest that major urban systems in developed countries cannot be characterized by a monotonically increasing distribution of ranks in larger cities, as predicted by advocates of Zipf's law. In fact, Richardson (1973) suggests that the variety of existing structures prevents any one power law from universally prevailing and being preferable in the description of all urban systems.

The critiques to the universal validity of Zipf's law have been substantiated both theoretically and empirically. From a theoretical point of view, Arshad, Hu, and Ashraf (2018) argue that Zipf's law is not always observable even for upper-tail cities, that is, large metropolitan areas. From an empirical perspective, instead, the meta-analysis discussed in Nitsch (2005) shows that over a panel data set of 515 estimates from 29 studies, the estimated Zipf coefficient is significantly larger than -1, unlike what Gabaix (1999) argues. The same point is made in Giesen, Zimmermann, and Suedekum (2010), who find that most evidence available on Zipf's law holds for population distributions among very large metropolitan areas but not for smaller settlements.[2]

Along the same lines, Soo (2005) finds that Zipf's law is empirically rejected more than on a purely random basis. This result is further substantiated in Black and Henderson (2003), who, on the basis of long run US data, find that Zipf's law does not hold in the US urban system. Even though there seems to be little mobility, the US case does provide some evidence of concentration in the upper tail of the city size distribution. Besides, traded services seem to be concentrated in very large cities, which makes a rather strong case for the lumpiness of high-level functions.

Why then do so many studies converge on the universal validity of Zipf's law? Eeckhout (2004) argues that the relationship between rank and population show a better fit with a Pareto distribution than a lognormal distribution (underlying Zipf's law). The two distributions behave very similarly in the upper tail, thus making it virtually impossible to distinguish between them for very large cities. In the same fashion, González-Val et al. (2015) conclude that the double Pareto lognormal distribution is, according to most statistical choice criteria and for most urban systems analyzed, the distribution that best fits urban structures.

The two views—Zipf's law, on the one hand, and models of asymmetric structures requiring different statistical distributions, on the other hand—are seemingly irreconcilable. While both approaches are based on spatial equilibrium, the former is a world of marginal changes in functions of increasing complexity, thus creating a world of continuous ranks. The latter is instead reminiscent of the world described in Christaller (1933) and Lösch (1940), whereby spatial equilibrium is characterized by spatial friction, and goods and services are produced only when rank-specific thresholds of production are reached, that is, when a minimum demand exists allowing production to be profitable. In this world, because of competition, only few centers achieve scale economies, thus managing to stay on the market. This second view of the urban system is spiky: as we move up the urban hierarchy, each layer of the size distribution accommodates a smaller number of cities, and, in the strict Christaller typification, hosts all functions proper for that layer, plus all other functions typical for lower ranks. This approach is related to work in economic geography dealing with spatial inequalities and the polarization of income levels along different layers of the rank-size distribution (Marchand, Dubé, and Breau 2020).

[2]Technical Appendix A.1 in the online material zooms in on the US and European urban system, highlighting that indeed Zipf's law only holds when limiting the analysis to the subsample of medium and large cities. Technical Appendix A.2 in the online material presents the rank evolution in Italian cities in the period 1971–2011.

Some recent attempts have been made to theoretically conceive urban systems that simultaneously meet the ideal world behind Zipf's law while also leaving room for the lumpiness of urban functions. One such example is Tabuchi and Thisse (2011), who present an NEG model leading to the emergence of urban systems with the desired regularities in terms of size and goods supplied. This result is obtained on the basis of a monopolistically competitive market for manufacturing industries with lowering transport costs causing a large number of small cities whereby a subset of those specializes at the expense of others. Along the same lines, Mori and Smith (2015) justify the lumpiness of urban ranks on the basis of demand externalities and of the synchronization between industries with smaller and larger markets, while Fujita, Krugman, and Mori (1999) show that the emergence of Christallerian ranks is compatible with a general equilibrium model with adjustment dynamics.

Determinants of Changes across Ranks

A common conclusion in the city size literature is that urban systems evolve at a surprisingly slow rate. Evidence suggests that past employment density is by far the most important explanatory factor for determining the present density of jobs, both at the macro (Krugman 1991) and micro (Redfearn 2009) scales. The long time needed for cities and urban systems to adjust to exogenous shocks is due to several factors such as housing durability (Glaeser and Gyourko 2005), transaction costs in the formation of intercity networks (Alderson, Beckfield, and Sprague-Jones 2010), persistence and polarization of human capital levels (Pred 1975; Berry and Glaeser 2005), and industry-specific shocks (Rossi-Hansberg and Wright 2007), among many.

Yet, according to the continuous rank approach, over the long run some variation in relative city rankings does take place, which we plan to exploit in the empirical section of this article. Cities can climb on the hierarchy by attracting a skilled workforce (Shapiro 2006), investing in higher-quality transportation infrastructure (Beeson, DeJong, and Troesken 2001), and increasing the quantity and quality of amenities they offer (Carlino and Saiz 2019). These determinants explain relative changes in the city's positioning within their urban systems.

A discrete rank approach, instead, has been analyzed in a more in-depth way by an equally large literature. Few works bringing forward Christaller's and Lösch's ideas deal with the way urban systems evolve altogether, without fully highlighting the determinants of such changes. This is the case in Parr (1981), who argues that a central place ranking can change via the "formation of a new level of the hierarchy, the modification in the extent of a level, and the disappearance of a level" (Parr 1981, 97). Similar arguments are proposed in Preston (1985), suggesting that Christaller's model has been unfairly categorized as inherently static in nature, while being instead much more prone to interpret urban systems dynamics than commonly held, a view that White (1974) also proposes.

A lively debate instead exists around the determinants of the way cities move across the Christallerian hierarchy. An early contribution in this vein is Camagni, Diappi, and Leonardi (1986), who propose a Supply-Oriented Urban DYnamics (SOUDY) model of urban growth, arguing that cities make structural leaps across the hierarchy only if capable of substantially increasing high-level urban functions. High-level urban functions are treated as an urban innovation factor in the form of private and public entrepreneurship. In their turn, higher-order functions increase (1) as cities enjoy sheltered local markets, thereby reducing minimum thresholds for such functions to appear; (2) as the functions diffuse from cities of higher rank located in close geographic proximity; (3) as cities manage to diversify their industrial structure; (4) because of external demand thresholds.

One of these predictions has been revamped by a recent reprise of the concept of borrowed size (Alonso 1973). In this view, small cities enjoy the perks of larger urban areas without incurring the costs associated with large size by being located close to large urban areas. Camagni, Capello, and Caragliu (2016) add a distinction between borrowed functions and borrowed size; this will be important for our own empirical analyses. At the theoretical level, through the population potential assured by a regional urban system, borrowed size refers to the advantages deriving from a diversified labor supply, from a larger market of final goods, and population spillovers from larger cities. Borrowed functions refer instead to the advantages stemming from a wider labor demand, from the greater accessibility of services, and also from the physical spatial spillovers of functions from larger cities.

Most literature dealing with urban growth explains it by invoking static agglomeration economies as the main sources of urban dynamics. However, city size is not the only source of urban benefits. High-level functions, borrowed size, the participation of the city in the urban system through intercity networks (Capello 2000; Taylor and Derudder 2015) can generate benefits from *external* scale economies, attracting more population and economic activities, and therefore foster city growth, in particular in cities enjoying absolute advantage (Scott 1992).

A shortcut has recently been identified in this literature: the presence of increasing returns to urban scale only indicates the superior level of productivity of large cities, not necessarily *growth* in productivity. Instead, dynamic agglomeration economies (time-derivative and not the size-derivative of urban benefits) are the main drivers of urban growth. If this is the case, a time comparison of the possible drivers of efficiency increases, especially in terms of the capacity to change some of the city's internal characteristics, is what explains the change in urban rank (Camagni, Capello, and Caragliu 2016).

In the case of discrete rank changes, empirical works on the determinants of the evolution of the urban hierarchy have also emerged. However, few empirical analyses to date have empirically verified the determinants of discrete rank changes. Moreover, no empirical attempts have been made to verify whether changes in continuous ranks are in fact explained by determinants that have been suggested for discrete changes.

In this article, we fill these gaps. We first apply a Christallerian perspective and adopt a framework that looks for the determinants of the evolution of Italian cities along an urban hierarchy organized around discrete ranks. Whether the city upgrades its urban rank depends on its improvements in structural characteristics: changes in higher urban functions, in borrowed size and functions, and in cooperation networks. We also test whether the same determinants explain continuous rank changes along the urban hierarchy.

We thus test the following two hypotheses:

H_1. The probability of increasing discrete urban rank positioning is positively associated with the change in structural characteristics of the city, namely, higher quality of functions hosted, larger borrowed size, larger borrowed functions, and higher-intensity of cooperation networks.

H_2. The probability of increasing changes in a continuous urban rank is explained by the same structural reasons as the probability of changes in discrete ranks.

In order to test these two hypotheses, we suggest a methodology to identify discrete ranks in the urban hierarchy, based primarily on a long-run Italian census database built for this purpose and ranging from 1971 to 2011 as explained in the next section. The empirical model and the data are described in "Empirical Specification, Data, and Indicators."

A Methodology to Identify Discrete Urban Ranks in the Italian Urban Hierarchy

Particular attention must be paid to the way discrete urban ranks are empirically translated in an indicator. In Camagni, Capello, and Caragliu (2021) this same method was first presented, and this was also applied to the Italian urban hierarchy in Capello, Caragliu, and Gerritse (forthcoming).

The method works as follows. For each decade of our database (1971 through 2011), cities are ranked in decreasing order of population. For each city, we calculate the percentage gap in population with respect to the city immediately above (Rome remained constantly on top of the hierarchy throughout the five decades analyzed). Consensus has now emerged on the asymmetric behavior of cities in this type of ranking (as explained in "Continuous or Discrete Ranks?"). In particular, we find a major inflection point for medium–large cities, and in particular for a size of around 1,000,000 inhabitants (where cities such as Bari, Palermo, Genoa, and Brescia are found). These cities turn out to be substantially smaller than the city immediately above (Turin, with more than 2,000,000 inhabitants throughout the estimation period).

We interpret this as a structural inflection point, which implies that the slope of the rank-size function becomes significantly flatter to the right of it. Consequently, we calculate an average slope for cities larger than the inflection point and a second slope for those smaller than this threshold. While the slope for cities smaller than the inflection point remains constant, equal to 3 percent for all five decades, the former tends to increase over time (from 13 percent in 1971 to 17 percent in 2011), providing indirect evidence, in line with what is found for the US in Black and Henderson (2003), of a hierarchization of the Italian urban system.[3]

Following Beckmann (1958), interpreting cities that are similar to one another, but not identical, within each Christallerian rank r_c, with a random distribution of their

[3]It is beyond our scope to fully discuss the spatial inequalities that arise from urban systems with persistence in top ranks and little movement in the right-hand side tail of the Zipf distribution. However, it is worth stressing that in the field of economic geography a lively debate took place on this issue. The latter also focused on the policies needed to correct the most severe consequences of these long-run trends, typically led by market forces that delivered less equal development than initially promised (see, e.g., Iammarino, Rodriguez-Pose, and Storper [2019 273] who speak of "place-sensitive distributed development policy").

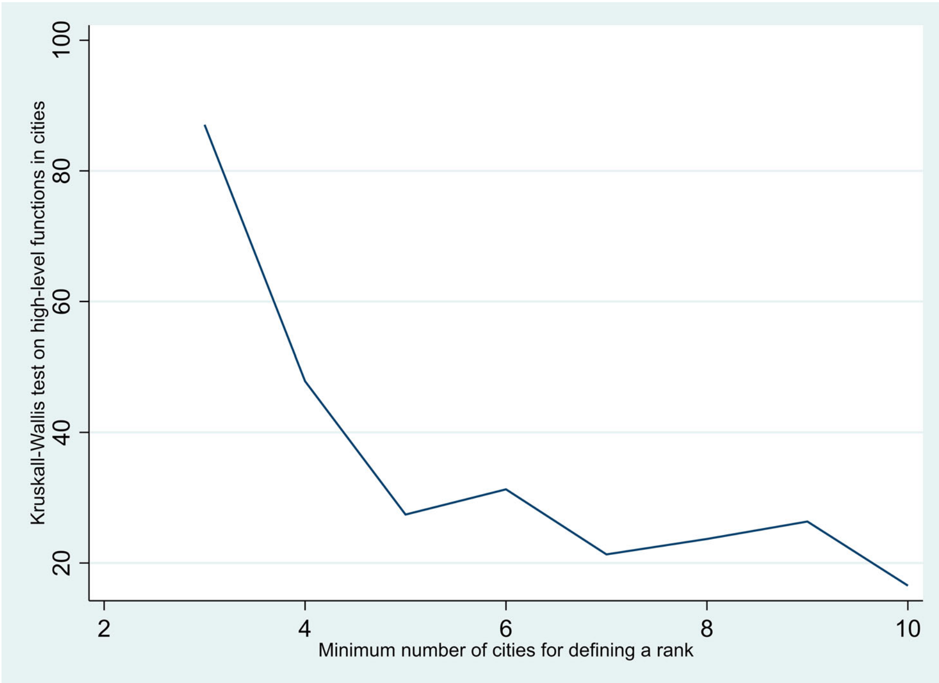

Figure 1. Kruskal-Wallis test for differences in high-level functions in ranks with increasing numbers of minimum cities.
Source: Authors' elaboration.

size around the average size of the original Christaller model, Camagni (2011) suggests interpreting as *reminiscences* of a Christallerian distribution all city groups whose regression line has a slope that is significantly lower than the overall Zipf curve. Consequently, boundaries between ranks are identified whenever population decreases with respect to the city immediately above on the continuous hierarchy are larger in modulus than these two average rank-size slopes. In the top tier of the distribution, this identifies three ranks (Rome, a second rank with Naples and Milan, and a third rank with Turin); these three classes remain constant over the five census periods, even in periods of increasing hierarchization.

Beyond the 3 percent threshold, we identify several ranks, but the excessive number of ranks prompted by the low average rank-size slope in the tails of the distribution required the adoption of an additional threshold on the minimum number of centers in each rank, set equal to three cities. The choice for three cities is supported by a Kruskal-Wallis (1952) statistical test for differences in the median in the distribution of ranks.[4] More precisely, we increased the minimum threshold for identifying ranks to the right of the inflection point. As shown in Figure 1, the statistic peaks at the three cities' threshold (implying that functions of cities belonging to each rank are more homogenous within each rank than to those of all other ranks), although the test

[4]The number of two centers was not taken into consideration since it would have not overcome the problem of too few centers in a rank.

remains significant even when varying the threshold. In this way, we identify from a minimum of nineteen ranks in 1971–91 to a maximum of twenty ranks in 2001–11.

Empirical Specification, Data, and Indicators

In the empirical analyses of this article we exploit time variation in city-level population to test our assumptions. In order to test H_1, discrete rank evolution in period t (DR) is explained by time-lagged changes of functions, of borrowed size, of borrowed functions, and of cooperation networks, in a previous period t-1 respectively,

$$\begin{aligned} DR_i = \alpha &+ \beta_1 Dfunctions_{i,(t-1)} + \beta_2 Dborrowed\ size_{i,(t-1)} \\ &+ \beta_3 Dborrowed\ functions_{i,(t-1)} + \beta_4 Dcooperation\ networks_{i,(t-1)}) \\ &+ \beta_5 Z_{i,(t-1)} + \varepsilon_{i,t-1} \end{aligned} \tag{1}$$

where indices t or t-1 refer to the change in a decade (1971–81, 1981–91, and 1991–2001), the last one time-lagged with respect to the dependent variable. i refers to a city, while *Dfunctions*, *Dborrowed size*, *Dborrowed functions*, and *Dcooperation networks* capture changes in the determinants of rank evolution. The Z vector includes additional control variables (depending on the different model specifications). Finally, DR is a measure of discrete rank evolution of a city in the urban hierarchy. This measure captures the discrete changes along the Christaller hierarchy. Descriptive statistics about rank evolution are presented in Technical Appendix A.5 in the online material.

For answering H_2, we calculate continuous ranks along with discrete ones. In fact, cities can move along the hierarchy in three main ways:

1. They climb along the Christaller hierarchy (i.e., their discrete ranking improves over time), but not in the Zipf one. This typically happens as a result of the hierarchization of the urban hierarchy (i.e., the creation of new ranks), typical of periods of economic growth (Parr 2017).
2. They improve along the Zipf hierarchy (i.e., their size grows faster, or decreases slower, than cities close in the absolute ranking), but this is not enough to move in the Christaller hierarchy.
3. Their ranking increases in both the Christaller and Zipf hierarchies, which happens as a result of the true improvement in city positioning, due to a substantial size increase pushing the city beyond the boundaries of its initial discrete rank.

The natural choice for dealing with this empirical problem is the multinomial logit model, which assumes no specific ordinal meaning attached to any given outcome, and allows empirically testing the impact of independent variables on the probability of reaching a given discrete outcome (Greene 2012).

To implement this model, we build a categorical variable for each period, equal to value 0 if the city climbed upward neither in the continuous (Zipf) nor in the discrete (Christaller) distribution; value 1, when it climbs in the Christaller distribution only;

value 2, when the city moves upward only in the Zipf distribution; and value 3, when a city climbs upward on both hierarchies. We can thus test the impacts of the structural changes in urban features on the probability to reach outcome 3 as a difference with respect to all other outcomes.

The database is mostly built on the basis of Italian Statistical Institute (ISTAT) population census data. Data cover the period 1971–2011. Population census data present the advantage of allowing a more detailed breakdown of the workforce, although the data also introduce a potential bias in particular for cities where people live but do not work.

This issue is minimized by the choice of the spatial unit of reference. We choose NUTS3[5] regions as they represent a good proxy for the commuting flows of workers, while also allowing comparison across five decades.[6] Data collected are summarized in Table 1.

Data have been harmonized across two main dimensions:

1. NUTS3 regions. In Italy, NUTS3 have changed classification for administrative reasons. In 1971 the country was organized into 94 units, while over time this increased to a maximum of 110 at the time of the last census reviewed (2011). Data have been harmonized backward, that is, holding the 2011 definition constant and assigning data of each NUTS3 region splitting over the prior decades to the NUTS3 regions emerging from it, according to the population share of each NUTS3 region within the larger spatial unit.
2. ISCO88 categories.[7] The definition of high-level functions has also changed across different censuses. The 1971 and 1981 censuses are organized according to the ISCO58 classification, while from the 1991 census, the ISCO88 classification has been adopted. For allowing time comparisons, we selected ISCO professions 1 and 2, including senior officials and legislators, managers, and professionals, and adopt the share of ISCO 1 and 2 professionals as a measure of high-level functions. This broad classification remained fairly constant over the five decades analyzed. As will be further explained in "Empirical Results," moreover, estimates will be split in two subsamples (1971–81 and 1991–2011) whenever dealing with changes in high-level functions.

Borrowed size is calculated as a population accessibility potential. In other words, for each region i, borrowed size is measured as the spatial lag of population levels in all other regions j, discounted by geographic distance between i and j (Eq. 2), plus the

[5]The NUTS classification (nomenclature of territorial units for statistics) is EUROSTAT's system for classifying subnational statistics. It ranges from level 0 (country data) to level 5 (local administrative units, or LAUs).

[6]Technical Appendix A.4 in the online material presents a number of robustness checks to further support this choice, as well as a test of the sensitivity of our findings to the choice of alternative geographies.

[7]ISCO stands for "International Standard Classification of Occupations" and has been released by the International Labor Organization for classifying jobs according to their skill intensity.

Table 1

Variables, Indicators, and Time Availability in the Data Base

Variable	Indicator	Years Available
Urban rank	Discrete variable measuring the city's positioning in the discrete/Christallerian hierarchy	1971, 1981, 1991, 2001, 2011
High-level functions	Percentage of ISCO88 professions 1 and 2 over total population	1971, 1981, 1991, 2001, 2011
Borrowed size	Spatial lags of population in other cities discounted by geographical distance plus internal city size	1971, 1981, 1991, 2001, 2011
Borrowed functions	Spatial lags of high-level functions in other cities discounted by geographic distance plus internal city functions	1971, 1981, 1991, 2001, 2011
Cooperation networks	Spatial lags of high-level functions in other cities discounted by cooperation distance	1971, 1981, 1991, 2001, 2011

size of city i:

$$\textit{borrowed size}_i = \sum_{j=1}^{n} \frac{pop_j}{d_{geo_{i,j}}} + pop_i \tag{2}$$

As Camagni, Capello, and Caragliu (2016) argue, cities may benefit from being close to other urban areas for two main reasons. On the one hand, cities benefit from having access to a large market, in line with the Central Place Theory. The internal size of the city must also be included, in that without correcting for this element, large cities would get little benefit from being close to other smaller areas that nevertheless do increase their local markets. However, they may also exploit proximity to high-level functions available in nearby urban areas. This second indicator is the so-called borrowed functions (Camagni, Capello, and Caragliu 2016). For each city i, this is calculated as the percentage of high-level functions in all other cities j, discounted by geographic distance between each city i and all other cities j, plus the high-level functions of city i (Eq. 3).

$$\textit{borrowed functions}_i = \sum_{j=1}^{n} \frac{\textit{high level functions}_j}{d_{geo_{i,j}}} + \textit{high level functions}_i \tag{3}$$

In both Eqs. (2) and (3), we measure geographic distance as pure geodesic distance between NUTS3 centroids. This feature does not change over time and enters exogenously in these two indicators, with the aim of capturing the spatial frictions hampering positive market size and functions effects.[8]

Lastly, as posited by urban networks theory, cities may benefit from gaining access to long distance cooperation networks, that is, the set of selected long-distance relations allowing each city to gain access to spatially remote benefits through cooperative behavior.

Eq. (4) shows that our measure of *cooperation networks* for each city i is obtained summing high-level functions in cities j discounted by an inverse measure of cooperation intensity ($^{d}coop_{i,j}$).

$$\textit{cooperation networks}_i = \sum_{j=1}^{n} \frac{\textit{high level functions}_j}{d_{coop_{i,j}}} \tag{4}$$

Unlike Camagni, Capello, and Caragliu (2016), who use Framework Programme coparticipations,[9] the long time span covered in our data does not allow the use of this indicator. Thus, we resort to copatenting intensity between cities. We exploit the

[8]For future work, the role played by changing transportation infrastructure in minimizing physical distance among selected nodes of, for example, fast railway connections and flights could be analyzed, and the robustness of our findings concerning borrowed size and functions tested in the light of the relevant evolution of the Italian network over the past half century.

[9]"The Framework programmes have been the main financial tools through which the European Union supports research and development activities covering almost all scientific disciplines. FPs are proposed by the European Commission and adopted by Council and the European Parliament following a co-decision procedure" (European Commission 2022)

information contained in the OECD RegPat database. This registers all patent applications to the European Patent Office from 1979 to 2017. Each patent bears information on the names of the inventors and the owners of the patent, along with their location. We counted the sum of all patent applications jointly written by individuals located at least in two NUTS3 regions, for each decade in the sample, row-standardizing this matrix. The inverse of this matrix is used as a cooperation distance measure for calculating cooperation networks as suggested in Eq. (4).

Empirical Results

Structural Determinants of Urban Hierarchy Evolution

Table 2 presents the result of the estimates of Eq. (1), where the structural determinants of hierarchical change are time derived. In Table 2, increases in high-level functions, in borrowed size, in borrowed functions, and in cooperation networks are included in columns 1 through 5, respectively (columns 1 and 2 break down the time sample in two, one subsample for 1971–81 in column 1 and one for 1991–2011 in column 2).[10]

The results mostly confirm the expectations discussed in "Structure and Determinants of Evolution of Urban Hierarchies." They suggest that the evolution of cities in higher ranks of the urban hierarchy depends on

- their capacity to host new superior functions, in line with Camagni, Diappi, and Leonardi (1986), and underlining the main message that the Central Place Theory suggested for a static approach that higher-level functions are hosted by cities belonging to higher ranks; this effect appears larger in the second half of the half-century observed in our estimates;
- their capacity to expand their size (market) thanks to nearby cities;
- the capacity of nearby cities to increase their high level functions.

This last point deserves specific attention, in that it depicts a world of increasing complexity. In seeking to maximize the returns to local amenities, and foster agglomeration economies, policy makers cannot ignore the context where these territorial externalities emerge. The relative positioning of cities can represent both a source of advantages as well as a curse that may in the long run hamper efforts made at local scale only.

Unexpectedly, increases in cooperation networks are instead negatively associated with rank increases. Apparently, cities face lower incentives to take on functions and the proper roles of superior ranks, when they increase their access to long-distance cooperation networks that increase urban benefits without incurring local agglomeration costs.

Lastly, within each rank, cities tend to achieve higher ranks as their size increases. In other words, for all cities belonging to the same rank, the probability of reaching higher ranks depends also on their initial size, which acts as a facilitating factor.

[10]Additional robustness checks focusing on the role of these same explanatory variables in periods of generalized economic growth, and for different layers of the urban hierarchy, are presented in Appendix A.3 in the online material.

Table 2

Determinants of Structural Changes along the Christaller Hierarchy

Dependent variable: changes in discrete urban ranks

Model	(1) 1971–81	(2) 1991–2011	(3) 1971–2011	(4) 1971–2011	(5) 1971–2011
Urban population	-0.295*	-0.667*	-1.36***	-0.982***	-1.56***
	(-2.41)	(-2.13)	(-4.94)	(-5.43)	(-4.92)
Initial urban rank	0.219***	0.100**	0.279***	0.219***	0.321***
	(11.43)	(3.08)	(9.87)	(9.96)	(10.79)
Decadal change of high-level functions	5.511**	11.48***	-	-	-
	(2.88)	(13.00)			
Decadal change of borrowed size	-	-	320.4***	-	-
			(6.90)		
Decadal change of borrowed functions	-	-	-	17.74***	-
				(20.74)	
Decadal change of cooperation networks	-	-	-	-	-7.891***
					(-13.80)
Constant	-0.237	-0.894***	-2.787***	-1.179***	-2.583***
	(-1.21)	(-4.61)	(-12.15)	(-6.87)	(-11.99)
Observations	110	330	440	440	440
Adjusted R^2	0.534	0.456	0.26	0.629	0.264

Notes: t statistics in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Identification Issues

Our results suggest that changes in high-level functions are instrumental in explaining leaps of rank among cities. One concern is that employment in high-level functions is a consequence of the city's (relative) size, instead of its cause. As cities grow, they may take over the role of regional centers and generate the functions demanded.

In order to exclude this reverse interpretation of the results, we report estimates from an instrumental variable strategy. We use two sources of variation in local employment in high-level functions that are arguably not explained by the local demand for employment in such functions. Both variables derive from a shift-share reconstruction of the variable.

The first instrument is the national change in employment in different functions (i.e., ISCO classes) projected on the start-of-sample specialization of every city. The employment share of ISCO class o in area i at time t is $s_{o,i,t} = \frac{E_{o,i,t}}{E_{i,t}}$, where $E_{o,i,t}$, which is the local employment in ISCO o out of the total local employment at a given time. Next, we predict the local ISCO employment share by projecting the national employment share changes on the start-of-sample local employment share of the ISCO class. The national change in the ISCO employment share is $s_{o,t}/s_{o,1971} = \frac{E_{o,t}}{E_t} / \frac{E_{o,1971}}{E_{1971}}$, where $E_{o,t}$ is the national employment in ISCO o in year t, and E_t is the national employment in year t; and $E_{o,1971}$ is the national employment in ISCO o in year 1971, and E_{1971} is the national employment in year 1971.

The prediction for the ISCO o employment share in location i is $\widehat{s_{o,i,t}} = s_{o,i,1971} * \frac{s_{o,t}}{s_{o,1971}}$. This prediction is constructed out of local initial specialization and national ISCO-level growth rates and hence unaffected by location-specific growth rates in function-specific employment. Regressions of $s_{o,i,t}$ on $\widehat{s_{o,i,t}}$ have coefficients close to 1, and the r-squared varies from 0.45 to 0.84. In the final step, we add up the predicted ISCO employment shares in high-level functions (ISCO 1 and 2) by location and year to serve as the instrument.

The second instrument derives from industry-level demand shocks for high-level jobs. The intuition is that areas specialized in industries that later developed a demand for high-level occupations will develop higher-level functions. This demand is simply driven by their exposure to technological change at the industry level, but not to local economic shocks. To develop this point, consider the following expression for the share of high-level (ISCO 1 and 2) employment of a city, which predicts high-level occupation demand due to industry exposure: $s_{hl,i,t} = \sum_j s_{hl,j,t} * s_{i,j,t}$, where $s_{hl,j,t}$ is the share of employment in industry j at time t that is a high-level occupation, and $s_{i,j,t}$ is the employment share of industry j in total employment in location i. Hence, $s_{hl,i,t}$ is simply the average share of high-level employment weighted across local industries. High-level employment changes over time may follow from (Eq. 5)

$$s_{hl,i,t} = s_{hl,i,1971} + \sum_j \Delta s_{hl,j,t} * s_{i,j,1971} + \sum_j s_{hl,j,1971} * \Delta s_{i,j,t} + u, \tag{5}$$

where $s_{hl,j,1971}$ is the start-of-sample local, high-level function employment in i; and the consecutive terms describe changes over time as driven by industry-level changes in occupational demand, local industrial composition changes, and their interactions captured in u. In particular, $\Delta s_{hl,j,t}$ is a location-independent change in industry j's employment in high-level occupations; $\Delta s_{i,j,t}$ is a change in the local employment share of industry j; and u is the interactive term, which one might also use to include other unobserved city-level shocks to high-level occupation employment. The local change in industrial structure, $\Delta s_{i,j,t}$, is likely driven by local economic shocks that might also explain a city's size and rank. By construction, u is, too. Hence, we focus our instrument on the changes in local high-level employment that are explained exclusively by national developments of the employment shares of high-level workers across industries, keeping the local industrial composition constant: $s_{hl,i,1971} + \sum_j \Delta s_{hl,j,t} * s_{i,j,t}.s_{hl,i,t} s_{i,j,t} s_{hl,i,t} = \sum_j \beta_j s_{i,j,t} + \varepsilon \beta_j s_{hl,j,t}$.

Both instruments employ initial conditions in the city when constructing the instrument: $s_{o,i,1971}$, and $s_{hl,i,1971}$, the initial ISCO1, ISCO2, or overall high-level employment shares. These initial conditions may point to a local specialization that is symptomatic of other growth prospects. These initial conditions are no major concern for the exogeneity of the instruments: the regressions explain rank changes and not levels, thus differencing out initial conditions. To further rule out that long-run trends correlated to the start-of-sample specialization of cities violate the exogeneity of the instrument, we estimate the regression conditional on city-level fixed effects. In a change specification, this strategy controls for the average changes over time and identifies the coefficient of high-level functions from deviations in its change from the long-run trend.

Table 3 displays the results of the instrumented baseline regressions. Columns 1 to 4 show the impact of high-level function levels on rank changes. The instrumented coefficient (32.61) is around 20 percent higher than its noninstrumented equivalent (26.61). The Kleibergen Paap F-statistics shows instrument relevance, and there is no sign of overidentification in the Hansen test.

The regression results are similar when introducing city-level fixed effects that difference out variation from initial condition in the instrument. The results do not differ much by instrument—the coefficients show little change, and both instruments are individually relevant.

Results from columns 5–8 in Table 3 show that changes in high-level functions employment at the city level predict change in ranks. In this case, the decadal change in high-level occupation employment is instrumented with the decadal change in the respective instruments. A change in sample standard deviation in high-level functions (11 percentage points) is associated with a significant though small probability of a rank change (of 0.02 points). As before, the instruments are relevant and show no sign of overidentification; and the inclusion of fixed effects has only marginal impacts on the coefficients. The coefficients resulting from the use of individual instruments in columns 7 and 8 vary somewhat more by instrument than they did in columns 3 and 4, but no conclusions change qualitatively.

Determinants of Continuous vs. Discrete Rank Evolution

A further round of empirical estimates is run to test whether the expectation we had on different determinants explaining continuous rank changes are empirically verified (Hypothesis 2). Table 4 reports the analyses with the same independent variables as

Table 3

Structural Determinants of Change in Discrete Urban Hierarchical Ranks: 2SLS Estimates of Eq. (1)

Dependent variable: changes in discrete urban ranks

Model	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Share of high-level urban functions	32.61***	32.89***	31.60***	33.45***	-	-	-	-
	(1.96)	(1.95)	(3.41)	(2.44)				
Decadal change of high-level functions	-	-	-	-	16.44***	16.38***	18.23***	15.89***
					(1.06)	(1.05)	(1.84)	(1.21)
Constant	-5.64***	-	-	-	-0.12*	-	-	-
	(0.34)				(0.07)			
Observations	440	440	440	440	330	330	330	330
Province FE	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Kleibergen Paap F-stat	556***	739.4***	122***	331.9***	371***	326.9***	79.56***	339***
Hansen J	0.234	0.188	-	-	1.23	1.255	-	-
p-value	0.628	0.664			0.267	0.263		
Province ids	-	110	110	110	-	110	110	110
Shift-share	-	Yes	No	Yes	-	Yes	No	Yes
Industry demand	-	Yes	Yes	No	-	Yes	Yes	No

Notes: *t* statistics in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 4

Discrete vs. Continuous Evolution in the Italian Urban Hierarchy: Number of Cities in the Different Categories

	Change in continuous ranks		
Change in discrete ranks	0	1	*Total*
0	136	79	*215*
1	143	192	*335*
Total	*279*	*271*	*550*

Table 2 but with a different dependent variable, built, as described in "Empirical Specification, Data, and Indicators," on the basis of a continuous distribution of urban ranks. This entails the following process:

- For each decade, cities are first ranked in decreasing order of size, from 1 to 110;
- We identify continuous ranks (1 through 110) r_z following Zipf's law, and r_c the discrete rank (1 through 20) following Christaller's approach;
- Two dichotomous variables are built on the basis of r_z (Δr_z) and r_c (Δr_c) and calculated as follows:

$$\Delta r_z = \begin{cases} 1, \; if \; r_{z,t} > r_{z,t-1} \\ O \; otherwise \end{cases}$$

and

$$\Delta r_c = \begin{cases} 1, \; if \; r_{c,t} > r_c \\ O \; otherwise \end{cases}$$

This allows assigning each city in each decade one of the possible four outcomes:

1. City i moves up neither on the Zipf nor on the Christaller hierarchy;
2. City i moves up on the Zipf distribution but not on the Christaller hierarchy;
3. City i moves up on the Christaller distribution but not on the Zipf hierarchy;
4. City i moves up both on the Christaller distribution and on the Zipf hierarchy.

A cross-tabulation of these four outcomes is presented in Table 4.

Table 4 shows that while many cities climb on the continuous hierarchy (because of minor oscillations around long-run trends) without involving structural leaps, a nonnegligible number of cities actually behaves the opposite way. Movements across discrete ranks but not continuous ranks occur because of changes in the number of levels within the hierarchy. Parr (2017) posits that in periods of spatially widespread economic growth, hierarchies tend to be prolonged, thereby generating a higher number of ranks.

Finally, in order to test the robustness of the theoretical explanation of urban rank evolution summarized in "Structure and Determinants of Evolution of Urban Hierarchies," we calculate a categorical variable taking on value 0 if the city climbed upward neither in the continuous (Zipf) nor in the discrete (Christaller) distribution (i.e., $\Delta r_z = 0$ *and* Δr_c=0); value 1, when it climbs in the Cristaller distribution only (i.e., Δr_c=1 *and* $\Delta r_z = 0$); value 2, when it climbs in the Zipf distribution only (i.e., Δr_c=0 *and* $\Delta r_z = 1$); and, lastly, value 3 when a city climbs upward on both hierarchies (i.e., $\Delta r_z = 1$ *and* Δr_c=1). We can thus test the impacts of the structural changes in urban features on the probability of reaching outcome 3 as a difference with respect to all other outcomes. Results based on fitting a multinomial logit model on the same specification as Eq. (1) are shown in Table 5.

An interesting corollary of this empirical specification is that, by assuming outcome 0 (cities do not climb in either hierarchy) as the base case, we should observe a positive and significant effect of the variables suggested as causes of structural leaps in the Christaller hierarchy, and in particular of changes in high-level functions, only for the section showing determinants of increases in the probability of reaching outcomes 1 and 3 (i.e., when the city increases its positioning in the Christaller hierarchy, either with, or without, improvements in the Zipf one).

The results, presented in terms of marginal effects, confirm the positive role played by changes in urban functions (Model 1, for the last three decades), borrowed size (Model 2), and borrowed functions (Model 3) in driving structural leaps across the hierarchy.

Table 5 also provides indirect evidence about the theoretical discussion on determinants of continuous and discrete rank changes. Changes in high-level functions explain only the probability of achieving outcome 1 (the city climbs on the Christaller hierarchy, even though it does not in the Zipf one) and outcome 3 (the city climbs in both hierarchies). This is a rather telling result: only structural changes in the spatial distribution of high-level functions are associated with structural leaps across discrete ranks. In other words, results provide negative evidence about our second research hypothesis: increasing changes in a continuous urban rank are *not* explained by the same structural reasons as changes in discrete ranks.

To test the prediction that high-level functions cause city rank improvements mostly for cities that already have high-level functional roles, we also report coefficient estimates across the distribution of high-level function intensity. Figure 2 plots the marginal effects at means of discrete changes in urban functions (measured at their quintiles, x-axis) on the probability of moving from outcome 1 to outcome 3, when cities climb both the discrete and continuous hierarchies. Larger decadal high-level functions changes improve the probability of a structural leap. The estimated coefficient becomes larger over the distribution of high-level change: moving from the bottom to the twentieth percentile improves the probability by about 2 percent, but moving from the third to the fourth quintile improves the probability by 13 percent (= 18-5). This suggests a lumpy role of high-level function in the urban evolution and in particular that the impact magnifies a city's place in the distribution in the high-level function change.

Table 5

Determinants of Structural Changes along the Christaller and/or Zipf Hierarchy

	(1) Structural Leaps I (Last Three Decades)	(2) Structural Leaps II	(3) Structural Leaps III	(4) Structural Leaps IV
Dependent variable: probability that cities improve only in the Christaller hierarchy				
Urban population	-1.51**	-1.41***	-1.29***	-1.60***
	(-3.09)	(-4.48)	(-3.48)	(-3.93)
Initial urban rank	0.646***	0.398***	0.491***	0.476***
	(3.86)	(7.62)	(6.51)	(7.07)
Decadal change of high-level functions	65.53***			
	(3.65)			
Decadal change of borrowed size		107.7		
		(1.65)		
Decadal change of borrowed functions			47.86***	
			(5.07)	
Decadal change of cooperation networks				-16.92***
				(-8.89)
Constant	-6.219***	-3.083***	-3.442***	-3.895***
	(-3.37)	(-7.33)	(-5.21)	(-6.73)
Dependent variable: probability that cities improve only in the Zipf hierarchy				
Urban population	-3.14*	-9.27***	-1.35***	-8.74***
	(-2.21)	(-3.80)	(-3.75)	(-3.74)
Initial urban rank	0.307**	0.134**	0.180***	0.127**
	(3.01)	(2.74)	(3.36)	(2.78)
Decadal change of high-level functions	1.652			
	(1.33)			
Decadal change of borrowed size		-139.6		
		(-1.89)		
Decadal change of borrowed functions			2.414	
			(1.47)	

Decadal change of cooperation networks				-2.193
				(-0.90)
Constant	-1.465***	-0.937**	-1.116**	-1.104***
	(-3.77)	(-2.78)	(-3.18)	(-3.55)
Dependent variable: probability that cities improve both in the Zipf and in the Cristaller hierarchy				
Urban population	-4.66**	-5.54*	-3.72*	-5.35**
	(-2.80)	(-2.50)	(-2.29)	(-2.68)
Initial urban rank	0.923***	0.695***	0.677***	0.741***
	(5.05)	(5.30)	(6.41)	(6.20)
Decadal change of high-level functions	67.35***			
	(4.20)			
Decadal change of borrowed size		61.00		
		(0.69)		
Decadal change of borrowed functions			44.73***	
			(5.37)	
Decadal change of cooperation networks				-15.50***
				(-7.56)
Constant	-8.478***	-4.627***	-4.698***	-5.329***
	(-5.07)	(-9.70)	(-7.90)	(-8.93)
Observations	330	440	440	440
Pseudo R^2	0.38	0.15	0.34	0.22

Notes: *t* statistics in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

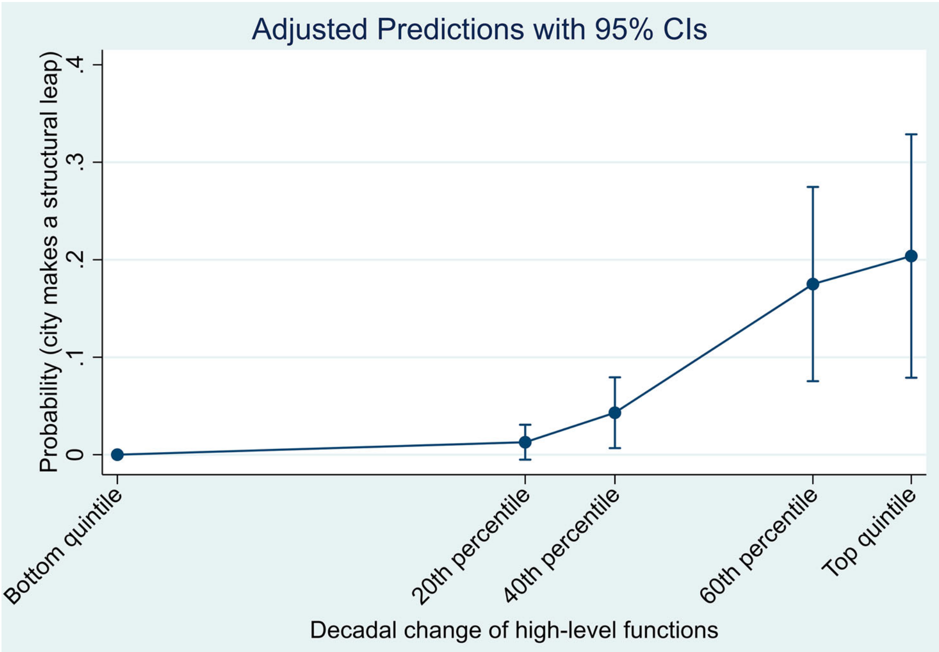

Figure 2. Marginal effects of changes in urban functions on the probability to climb on both the continuous and discrete urban hierarchy.
Source: Authors' elaboration.

Conclusions

By dealing with the determinants of the urban hierarchical evolution, the article has entered the debate existing between two major approaches. On the one hand, most neoclassical theories view urban systems through the lens of continuous ranks in which the evolution within the urban hierarchy is due to urban quality (such as infrastructure or human capital), and changes in the hierarchy occur due to city-level changes, irrespective of the positioning of each city within the hierarchy. On the other hand, the regional science literature originating in Christaller (1933) and Lösch (1940) views urban functions as an engine of development, where ranks of different functions emerge, and lumpiness surfaces because cities develop when they cross rank thresholds.

This article provides three main novelties with respect to the present debate. First, it is among the few to stress the structural characteristics that cause urban hierarchy evolution, highlighting the scant literature in the continuous rank's approach with regard to the discrete rank's one. Second, the empirical work adds to a long-standing tradition in the regional science literature, whereby urban characteristics have so far been used to explain urban growth, rather than the evolution of the urban system as a whole. Third, it enters the theoretical debate on the continuous or discrete nature of urban ranks, which are interpreted as complementary rather than juxtaposed approaches, and highlights, in an inductive way, whether changes in the continuous ranks are explained by the same determinants of discrete ranks' evolution.

Our analyses provide several notable conclusions. A first implication is that in order to sustain urban development through leaps within the urban hierarchy, cities need to attract high-level functions or to increase functions supplied by borrowing them from nearby urban areas. This result also holds when accounting for the possibility that urban size causes changes to urban functions.

A second result is the empirical identification of the determinants of structural change (leaps across discrete ranks). These include variations in high-level functions, borrowed size, and borrowed functions, while no positive contribution is found for cooperation networks.

A third and very relevant message is associated with the horse race between the same regressions being run on continuous and discrete measures of urban ranks. In the former case, explanatory variables suggested by the Central Place Theory literature provide no explanatory power, underlying once more that the change in discrete ranks is something profoundly different than changes in continuous ranks.

The main policy implications stemming from the above messages are threefold. First, planning for structural leaps in the urban hierarchy calls for investing in urban characteristics different from those leading to smooth improvements along the hierarchy. While the latter can be achieved by (even minor) improvements in human capital and infrastructure, the former request more structural investments in urban quality, by means of superior urban functions. Second, territorial externalities characterize urban systems. These must be properly accounted for in the process of designing policies. In the absence of this management, that is, by looking at each city specifically, one loses the big picture of urban performance. Market access and external demand still play a major role in determining urban evolution, and supraurban political entities are called for to coordinate and optimize the intensity of these externalities. Lastly, our results, in particular those related to the context conditions triggering external agglomeration economies (borrowed size and functions, and long-distance cooperation networks), suggest that in many cases, territorial externalities are increasingly taking place at the supralocal level. Therefore, policies seeking to maximize the returns to local amenities should not ignore the relevant role played by regional contexts, and address spatial policies so as to frame them within the broader context.

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