Knowledge economy clustering at the intrametropolitan level: evidence from Madrid

Abstract

Despite the increasing relevance of knowledge-based activities in the global economy, their spatial distribution at the intrametropolitan scale has rarely been studied. The aim of this paper is to shed light on the intrametropolitan spatial localisation of knowledge-based activities by assessing some of its main causal mechanisms, paying special attention to agglomeration economies and borrowed size (both questioned in the era of Information and Communications Technologies because of the theorised 'death of distance'), the controversial role of industrial diversity and specialisation (traditionally considered exclusive processes) and path dependence. The empirical application refers to the case of the Madrid urban region for the period between 2012 and 2017. This study area proves particularly appropriate for two main reasons. First, the area is a main urban region in the European and global urban systems. Second, the area is a good example of a multicore urban region with a traditionally strong metropolis. The results show that the knowledge economy remains strongly dependent on the size of the city itself (agglomeration economies) and of the surrounding areas (borrowed size), that the specialisation and diversity processes are complementary and appear at different scales and that, in the specialisation of certain areas in some knowledge economy activities, the city's trajectory (path dependence) plays an important role. The results of the present study have various practical implications for policymakers when considering not only strategies (and investments) to coordinate land availability, worker training, connections between research centres and companies and amenities but also strategies to coordinate with the surrounding municipalities (e.g. in terms of mobility or joint public and private projects).

Key words: knowledge-based economy, agglomeration economies, borrowed size, path dependence, multicore urban regions

1. Introduction

During the last decades, the spatial concentration of economic and social activities has drastically increased. Despite the negative externalities or diseconomies of large urban areas (in terms of land prices, congestion and pollution, among others), population and economic activities still tend to concentrate in main cities and urban regions (Glaeser, 2011; Giuliano et al. 2019; Crescenzi et al., 2019). This concentration benefits firms because of the presence of externalities (such as larger productivity) and knowledge spillovers. However, in the information economy era, the strength and nature of agglomeration economies have been questioned: whereas some studies defend the concept that information and telecommunications technology would reduce the need for being close, leading to fragmented and dispersed metropolises (Mitchell, 1996; Hamidi and Zandiatashbar, 2018), other scholars conclude that physical proximity is still important, as evidenced by Storper and Venables (2003) and Kijek and Kijek (2019) in knowledge-based economy.

Moreover, while traditionally, agglomeration economies were highly related to the secondary/manufacturing sector (and subsequently the service sector), since the 1980s and 1990s, these economies relate to the production, processing and diffusion of knowledge services (Lambooy, 1998; Wan Winden et al., 2007; Camagni et al., 2015a). This change stimulates research on the spatial distribution of the knowledge economy (KE) and the geographical characteristics that promote and enhance knowledge and innovation.

Nevertheless, previous studies on the topic of the KE present different limitations. First, in terms of the scope of the analysis, KE studies focus on determining their effects on the productivity, competitivity and growth of regions and firms, paying less attention to their nature and spatial distribution (Powell and Snellman, 2004; Uppenberg, 2010; Dima, et al., 2018). Second, in terms of the scale of the analysis, studies on the emergence and consolidation of the

KE have traditionally focused on national and regional scales (Henderson, 2010; Meijers and Burger, 2010; Camagni et al. 2015b) and have paid comparatively less attention to the intrametropolitan scale (Hall and Pain, 2006; Méndez and Tébar, 2011; Shearmur, 2012; Volgmann and Münster, 2018). Third, studies on the effects of economic crises on KEs are very limited, especially in countries in which the economic downturn has been more severe, such as in Southern Europe and Spain in particular (Knieling et al., 2016).

Considering these shortcomings, the purpose of this paper is to analyse and assess the main casual mechanisms of agglomeration economies that have an influence on the spatial distribution of KE at the intrametropolitan scale. This paper contributes to science with a new, comprehensive framework to understand the spatial distribution and nature of the KE based on three mechanisms until now studied separately (Raspe and Oort, 2006; Combes and Gobillon, 2015; Camagni et al., 2015b; Pino and Ortega, 2018; Crescenzi et al., 2019). The three mechanisms hereby studied are the borrowed size effect (both questioned in the era of the ICT because of the theorised 'death of distance'), the role of industrial diversity and specialisation and the influence of path dependence effects on the concentration and vocation of the KE at the intrametropolitan scale.

This paper is organised as follows. The second section presents the theoretical framework to understand the spatial logic of the KE. The third section introduces the study area and the methodological approach (including the variables, indicators and techniques that support our analyses). The results are presented and discussed in sections four and five, respectively.

2. Theoretical framework

Recent studies confirm that the location of the KE depends on demographic size, meaning that population growth leads to the greater presence of the KE (Shearmur and Doloreux, 2008, Pumain et al. 2009 or Escolano-Utrilla and Escalona-Orcao, 2017). This concentration of the KE in the largest cities is in response to different factors on the demand and supply sides. On

the demand side, large cities concentrate higher shares of consumers, with the KE benefiting from proximity to them and all types of services. Additionally, larger cities are generally more dynamic and perform economically better, allowing more business start-ups (Ženka et al., 2015). On the supply side, agglomeration economies are related to population size and density (Duranton and Puga, 2000); accessibility reasons also exist (Gallego and Maroto, 2013). Furthermore, KEs are located near skilled and experienced labour forces, which is their key input (Coffey and Shearmur, 1997) but also close to their principal suppliers (Camacho et al. 2013).

However, it is more appropriate to state that KE agglomeration depends on the relationships between economic and non-economic agents not only in the same city but also with the surrounding[1] ones (Porter, 1998; Boix and Trullen, 2007) or those within a spatial range of influence (Meijers and Burger, 2015; Volgmann and Rusche, 2019). This means overcoming the traditional general understanding of the unquestionable benefits of locating within larger cities and considering the benefits of spatial proximity (and city networks) and neighbouring agglomerations (Phelps et al., 2001). This understanding relates to the borrowed-size concept, which was first introduced by Alonso (1973)[2]: smaller cities within metropolitan contexts perform better because they profit from the agglomeration effects of larger cities in their surroundings.

Given this context, we establish our first working hypothesis: at the intrametropolitan scale, KE concentration does not follow a hierarchical logic but rather a functional one. This means that a city's rank in the metropolitan urban system is not only determined by its size but also is

[1] Or with those sharing high-functional relations.

[2] Scholars have subsequently developed this concept in terms of borrowed performance and borrowed functions (Meijers and Burger, 2015; Meijers, Burger and Hoogerbrugge, 2015; Camagni, Capello and Caragliu, 2015).

benefited by a network effect of surrounding small and medium-sized cities (through the borrowed-sized concept).

However, the spatial distribution of the KE could be explained not only by city size but also by other factors such as regional economic specialization and/or diversity. In this regard, although previous studies traditionally focused on determining whether specialisation (Marshall externalities) or diversity (Jacobs externalities) drives growth and innovation (Burguer et al., 2015; Harrison et al., 1996), recent scholars have concluded that these processes are not exclusive (van Oort, 2015; Paci and Usai, 2000). In other words, specialisation and diversity strategies lose value on their own, and future urban economic development results from the interaction between firms and cities. In this sense, our second working hypothesis is that, at the intrametropolitan scale, the specialisation and diversity of the KE are not selective but complementary processes, appearing differently at local versus metropolitan/regional scales.

Finally, because specialisation and diversity are complementary, it is necessary to understand the factors that make different places at the intrametropolitan scale function in different ways. According to van Windem et al. (2007: 525), 'the shift towards a knowledge-based economy seems to favour some well-endowed urban areas'; however, 'not all cities benefit equally' depending on national and local policies. Beyond the spatial and functional configuration processes of urban regions, the accumulative process evidenced in the spatial concentration of the population, economic activities, infrastructures and other facilities has illuminated the importance of the path-dependence process (Henning et al., 2013; Chong et al., 2020).

In this sense and in line with path-dependence approaches/theories, we could assume that the KE (its dynamism and growth) is influenced by the spatial trajectory of a city and by the public and private interventions developed in the past (Pierson, 2000). Consequently, cities with a traditionally high concentration of qualified workers, the presence of services and commerce and investments in certain facilities (such as cultural, educational or sport facilities) benefit the

location/concentration and growth of workers and firms related to the KE (Florida, 2002; Giuliano et al., 2019). Additionally, the quality (and variety) of activities and production factors and the quality of the infrastructure (and facilities) benefit innovative urban dynamics and the location of the KE (Camagni et al. 2015a; Chong et al., 2020).

In summary, this allows us to establish our third and last working hypothesis: KE growth is influenced by the previous existence of qualified workers, intermediary companies and infrastructure/facilities.

3. Study area and methodological approach

3.1. Study area and classification of knowledge-based activities

The empirical application refers to the case of the Madrid urban region, and the analyses span the period between 2012 and 2017 (what we call the post-crisis period[3]). As examined by previous studies (Solís et al. 2012; Solís et al. 2015), this urban region not only covers the autonomous region of Madrid but also spreads towards the adjacent provinces of Avila and Segovia (Castilla y León autonomous region) and Cuenca, Guadalajara and Toledo (Castilla-La Mancha autonomous region). With almost 8 million inhabitants, Madrid's urban system comprises 1,366 municipalities, although only 71 of them are over the threshold of 10,000 inhabitants[4] (see Figure 1). Considering that the KE is concentrated in municipalities over 10,000 inhabitants, our analyses focus on these 71 Madrilenian centres.

Insert Figure 1 here

[3] Although the crisis and post-crisis periods have been unequal in terms of economic, social and territorial effects depending on the spatial context, from an economic perspective, the crisis period in Spain occurred from 2008 to 2012/2013/2014. During these three years, the country witnessed slow economic recovery (as shown by macroeconomic data such as GDP, per capita GDP and employment growth). However, important challenges remain to be addressed, such as the reduction in risk premiums, public debt and socio-spatial inequalities (evidenced by the number of temporary jobs, high unemployment levels and considerable percentage of evictions).

[4] In Spain, according to the National Statistics Institute, the threshold of 10,000 inhabitants is used to differentiate between rural and urban municipalities.

During the study period (post-crisis), the tertiary sector witnessed greater growth than the primary and secondary ones. The KE followed a similar trend (see Table 1), accounting for 35-40% of the total number of firms and 40-45% of the total number of workers in 2017 in the Madrid urban region. However, although these data confirm the increasing importance of the KE, a comparison with other European countries and regions shows a necessary effort to reach international rates. According to EUROSTAT[5] data, although the KE accounted for 36% of the total Spanish economy in 2017, this rate reached 41% in the EU, 42.1% in Germany, 46.9% in France and 50% in the United Kingdom. This contrast also appears for the main European capitals, reaching 54% for the Berlin urban region, 53.2% for the Île de France and 59.2% for London.

Insert Table 1 here

One of the main limitations to analysing the spatial patterns of the KE is that, despite its increasing importance and impact on economic, social, environmental and territorial reorganisation, there is no precise or concise definition of it (Kemeny and Storper, 2014). During the last two decades, various activity sectors have become linked to the KE, and different classifications have been suggested. The first classifications considered financial, insurance and real estate (FIRE) services (Sassen, 1991) and knowledge-intensive business services (KIBS), distinguishing between professional KIBS (P-KIBS) and technology KIBS (T-KIBS) (Miles et al. 1995). Subsequent studies also considered KE services related to high-technology industries (Hecker, 2005), cultural and creative industries and other activities (Hesmondhalgh and Prat, 2005), such as educational or health activities (Miles et al. 2008). Considering these previous works, we suggest the following classification of KE activities (NACE-CODE -2 DIGIT- Rev. 2 (2009)).

[5] See https://ec.europa.eu/eurostat/web/products-datasets/-/htec_emp_reg2 and https://ec.europa.eu/eurostat/cache/metadata/Annexes/htec_esms_an3.pdf. See https://ec.europa.eu/eurostat/cache/metadata/Annexes/htec_esms_an3.pdf.

1. P-KIBS, including
    - 64 financial services, except insurance and pension funds
    - 63 information services
    - 65 insurance, reinsurance and pension funds, except compulsory social security
    - 66 activities auxiliary to financial services and insurance
    - 68 real estate activities
    - 69 legal and accounting activities
    - 70 headquarters activities; business management consulting activities
2. T-KIBS, including
    - 61 telecommunications
    - 62 programming, consulting and other activities related to computer science
    - 71 architectural and engineering technical services; technical tests and analyses
    - 72 research and development
    - 74 other professional, scientific and technical activities
3. HTI high-technology industries, including
    - 21 manufacturers of pharmaceutical products
    - 26 manufacturers of computer, electronic and optical products
    - 30 manufacturers of other transport material (including aeronautics and aerospace)
4. C&C cultural and creative industries, including
    - 58 editing/publishing
    - 59 motion picture, video and television programme activities, sound recording and music publishing
    - 60 radio and television programming and broadcasting activities
    - 90 creative, artistic and entertainment activities
    - 91 activities of libraries, archives, museums and other cultural activities
5. OTHER - Other knowledge economies activities, including
    - 84 public administration and defence; compulsory social security
    - 85 education
    - 86 health activities.

The data used for the analyses come from the number of companies and workers affiliated with social security at the municipal level, or 'Nomenclature of Territorial Units Statistics, NUTS-5', disaggregated according to the second level of the National Classification of Economic Activities (NACE-Code Rev. 2009). These data were provided by the Departments of Economy of the Madrid, Castilla-La Mancha and Castilla y León autonomous regions for 2012 and 2017. The period considered adds one more relevant aim to the paper: evaluating the spatial distribution of the KE during a post-crisis period.

3.2. Method

In the last two decades, the analysis of KE has been tackled from segmented approaches based on quantitative and econometric analyses, such as indicators, composite indexes, OLS regressions, cluster or factorial analyses (Hall and Pain, 2006; Raspe and van Oort, 2006; Combes and Gobillon, 2015). However, in our attempt to achieve an integrated characterisation of the growth and spatial distribution of KE, we suggest a multistep method based on some of the previous partial analyses:

(i) for assessing the effect of borrowed-sized, based on Meijer and Burger (2015) or Chica (2016), a regression model is proposed. Variables are nevertheless adjusted to the case study. Population, employment, number of firms, etc. (either of the city itself and of the surrounding cities) are considered to evaluate their agglomeration effect of KE spatial concentrations.

(ii) for characterising specialisation and diversity processes, following Méndez and Sanchez-Moral (2011) or Chica (2016), and based on an economic characterization of each city, a cluster analysis is suggested; and, finally,

(iii) for assessing the path dependence effect on KE concentrations, we also suggest a regression model. In this model, the independent variables are, on the one hand, the

location coefficient of skilled workers and knowledge-based activities concentrations (based on Volgmann and Münster, 2018) and, on the other hand, the Shannon-Wiener index of amenities/facilities (such as in Chong et al., 2020).

The following provides a more detailed explanation of the research method. The first step in our study aims to determine the concentration and dynamism of the KE in the post-crisis period, considering the effects of city size, borrowed size and distance to Madrid (our first working hypothesis). In doing so, a correlation analysis is developed in SPSS (version 24) for 2012 and 2017 (see Figure 2, including the dependent and independent variables). This correlation analysis is decomposed in two steps:

a) the first step evaluates the strength of the relation, in either 2012 or 2017, among both KE workers (KEwor) and KE companies (KEcom) with the independent variables (POB, COM, WOR, COMbz, COMbzKE, WORbz, WORbzKE and DISMad);

b) the second step evaluates, also for both temporal scenarios, the level of the relation among these variables but differentiates the type of KE (in this case, the dependent variables are P-KIBSwor, P-KIBScom, T-KIBSwor, T-KIBScom, HTIwor, HTIcom, HTIcom, C&Cwor, C&Ccom, OTHERwor and OTHERcom, and the independent variables are the same as for the correlation developed in the first step of the analysis).

Because the considered variables (the number of KE workers and the number of KE firms) do not follow a normal distribution, the Spearman's rho measure is used to study the correlation between the variables. By evaluating the value of this measure (and its significance), we consider a low/very low correlation between variables when rho is lower than 0.3, a moderate correlation when rho varies between 0.3 and 0.7 and a strong correlation if rho is higher than 0.7. For rho values lower than 0.1, we consider that no correlation exists between variables.

Insert Figure 2 here

In addition to determining the effect of borrowed size on the concentration of the KE for the entire urban region, attention is paid to externalities resulting from the disconnection between cities' demographic size and function (Meijers and Burger, 2015). In doing so, we develop the rank-size rule (in terms of both demographic and functional sizes – defined as the number of KE workers) for the 71 centres within the Madrid urban region. We then compare the position that each centre occupies in both rankings and the possible variations between 2012 and 2017. This comparison allows us to determine a) cities that exhibit lower levels of urban functions than other cities with similar or larger demographic sizes (negative externalities or agglomeration shadows) and b) cities that exhibit levels of urban functions that are more typical of larger cities because of the benefits associated with neighbouring cities' networks (positive externalities or knowledge spillovers).

The second step of our research focuses on the spatial distribution of the KE in terms of its specialisation or diversity within the Madrid urban region (focusing on the 71 centres). In this assessment, a cluster analysis is developed for the situation in 2017 (using the ArcGIS Grouping Analysis Tool, version 10.6). To avoid distorted results, Madrid is excluded from the analysis. The results[6] (both cartographical and statistical) provide clusters of cities that share similar concentrations of the different types of KE activities. By using the ArcGIS software to evaluate the optimal number of groups, for the case of KE companies, the value of 5 is found to provide the best group differentiation, with no identification of an optimal number of groups for the case of KE workers. Thus, the cluster analysis was only developed for KE companies. These clusters are then analysed in 2012 considering the share of each type of KE to capture

[6] The results are based on the number of groups specified (five for our case study), an analysis of the variables (P-KIBSwor, P-KIBScom, T-KIBSwor, T-KIBScom, HTIwor, HTIcom, C&Cwor, C&Ccom, OTHERwor, OTHERcom) and optional spatial constraints (that were not selected in our analyses to determine whether spatial location influences the location of KEs close to each other).

differences in the characterisation of clusters and the evolution of the specialisation and diversity of the KE.

The third and last step of our research aims to assess the path-dependence process, that is, how certain features, decisions and trajectories of the past (such as the previous/traditional concentration of skilled workers and knowledge-based activities as well as the existence of certain facilities and amenities) condition the recent growth and concentration of the KE and, thus, the specialisation or diversity of some places with regard to certain types of KEs. In conducting this analysis, we consider the situation for 2001 because of the more reliable information included in the Spanish Census for this year (in contrast to the last census of 2011).

The variables used from 2001 are (1) occupation level (according to the National Classification of Occupations of 1994 – NCO 94), (2) activity sector of the establishment (according to the National Classification of Economic Activity in 1993 – CNAE1993) and (3) type of retail space and facilities (see Figure 3). These variables allow us to characterise each of the 71 centres under study in terms of their past facilities and trajectories.

- The first variable classifies the occupation level into 9 types (Figure 3). For our analyses, we select the first four types (1. company management and administrations; 2. professional scientific and intellectual technicians; 3. support technicians and professionals; 4. administrative-type employees) because they are more closely linked with knowledge-based activities. Using these data, we obtain a location coefficient (LC_occu) that characterises each of the 71 centres:

$$LCij = (Eji/Ei)/(EjN/EN), \quad [1]$$

where Eji is the number of workers with occupation level j in centre i; Ei is the total number of workers in centre i; EjN is the total number of workers with occupation level

j in the entire Madrid urban region and EN is the total number of workers in the Madrid urban region.

- The second variable distinguishes thirteen types of activities, denoted by a letter. For our analyses, the activity sectors selected because of their link with knowledge-based activities are those denoted by letters J, K, L, M and N (Figure 3). Similar to the previous variable, we obtain a location coefficient (LC_act) that characterises each of the 71 centres under study in terms of the activity sector of the establishments.

- The third variable characterises retail spaces and facilities in 9 typologies. For our analyses, given their link with knowledge-based activities, we select those spaces characterised from 1 to 7 (health facilities, cultural and sports facilities, retail, office spaces and industry). For these data, we establish a location coefficient and a diversity index (Shannon index) for each of the 71 centres under study:

$$\text{I\_shannon} = -\sum_{i=1}^{S} p_i \cdot \log_2 p_i \,, \quad [2]$$

where S is the number of typologies (that is, 9) and pi is the share of retail spaces and facilities for each typology out of the total (for the entire Madrid urban area).

Once we have characterised each of the 71 centres of the Madrid urban area according to their past features (the working population' occupation level, establishments' activity sector and the type of retail space and facilities), a correlation analysis is developed (in SPSS version 24) to evaluate the influence of path dependence (the independent variables are the four location and diversity indices for each centre) on the current level of the KE (the dependent variables KEwor, KEcom, P-KIBSwor, P-KIBScom, T-KIBSwor, T-KIBScom, HTIwor, HTIcom, C&Cwor, C&Ccom, OTHERwor and OTHERcom).

Insert Figure 3 here

4. Results

4.1. Concentration and dynamism of the KE: effect of city size and distance to Madrid on the spatial distribution of the knowledge economy

In this first subsection, we analyse the spatial distribution of the KE in terms of both the city size and the distance to the metropolis (Madrid).

In addition to the concentration of the KE in municipalities with more than 10,000 inhabitants (see Tables 1 and 2), we observe the following tendencies;

- The expected prevailing role of Madrid within the urban region in attracting companies and workers, especially those related to the KE (accounting for more than 50% of the entire Madrid urban region; see Table 2); this role has been slightly reinforced in the post-crisis period.
- The influence of the urban hierarchy in the process of the concentration and growth of the KE: the larger the city size, the greater the importance/concentration of the KE; thus, in addition to the polarising role of Madrid, the concentration of the KE in small (between 10,000 and 50,000 inhabitants) and medium-sized (between 50,000 and 250,000 inhabitants) cities suggests the multicentric spatial character of the KE within the urban region; and
- Looking at the individual type of KE, whereas PKIBS, TKIBS and C&C services are located in a hierarchical pattern (concentrating in centres with a larger size), HTI and OTHER services follow a different spatial pattern; on the one hand, HTI activities are less concentrated in Madrid than in the surrounding medium-sized cities (see Table 2); on the other hand, OTHER activities are spread more throughout the urban region;

Insert Table 2 here

In contrast, this fact needs to be nuanced by including the effect of borrowed size and distance to Madrid. On the one hand, during the post-crisis period (2012-2017), the concentration of the

KE benefited from the sizes of the adjacent municipalities (in terms of the numbers of workers and firms), that is, by the borrowed-size effect (see Table A1 in appendix). This allows us to verify our first research hypothesis, confirming that *at the intrametropolitan scale, KE concentration does not follow a hierarchical logic but rather a functional one*. On the other hand, regarding the distance to the metropolis, it is evidenced that, in the post-crisis period for the Madrid urban region, the growth of the KE was less intense as the distance from Madrid grew (see Table 3 and Table A1 in the appendix).

Insert Table 3 here

4.2. Spatial distribution of the KE: specialisation vs diversity

There is a closed (and bidirectional) relationship between the KE (function) and the spatial layout (space). In this sense, the results of the cluster analysis developed for the Madrid urban region in 2017 show the importance of the clustered pattern of the KE across the study area (see Figure 4a). By distinguishing among PKIBS, TKIBS, HTI, C&C and OTHER, the coexistence and diversity of functions within the urban region can be determined at the local scale: centres are not specialised in a single type of KE service but, rather, different types coexist within the same city (see Figure 4a). According to the results obtained from the grouping analysis developed in ArcGIS, the five clusters of centres can be characterised as follows (see Figures 4a and 4b):

- Cluster 1: centres with average-low concentrations (standardised values between the Global Lower Quartile – Q1 – and the Global Median – Q2) of all types of KE firms;
- Cluster 2: centres with a high concentration (standardised values between the Global Upper Quartile – Q3 – and the Global Upper Whisker) in OTHER companies and a very high concentration (outliers or values over the Global Upper Whisker) in the rest of the types of KE firms;

- Cluster 3: centres with a high concentration in OTHER, PKIBS and C&C services and a very high concentration in HTI and TKIBS companies;
- Cluster 4: centres with average-high concentrations (standardised values between the Global Median – Q2 – and the Global Upper Quartile – Q3) of all types of KE firms;
- Cluster 5: centres with an average-high concentration in HTI services and a very high concentration in PKIBS, TKIBS, C&C and OTHER services.

Insert Figure 4 here

At the metropolitan scale, certain specialisation processes are identified following the traditional radio-concentric motorway system. In particular, the comparison of the cluster analyses in terms of firms, the concentration of KE services and the evolution between 2012 and 2017 (see Figures 4b and 5) shows that PKIBS, TKIBS, HTI and C&C firms tend to concentrate in clusters 2 and 3 (a total of ten centres). These centres are closer to Madrid – located in the first metropolitan ring. Although also of considerable importance, cluster 5 cities (including Historical Administrative Cities and municipalities over 150,000 inhabitants) concentrate considerable rates of KE firms (mainly in OTHER and PKIBS services). The lowest rates of KE firms appear in cluster 1 and cluster 4 cities (corresponding to centres more distant from Madrid). In addition, the location patterns of KE companies do not follow contiguity constraints.

Overall, at the intrametropolitan scale, we observe a certain clusterization in specific KE sectors, but also, at the local scale, each city has its own variety of KE activities. All this confirms our second research hypothesis (*that is, specialization and diversity are complementary processes*).

Insert Figure 5 here

4.3. Influence of path-dependence processes in the spatial distribution of the knowledge economy

The results previously presented in this paper show the growth and importance of the knowledge economy within the urban and metropolitan economy. However, although some centres benefit from knowledge spillovers, others suffer from an agglomeration shadow effect. Why does the effect of borrowed size occur in some cities and not in other cities? Why do some cities take advantage of the presence of neighbouring cities better than others? Although the answer is not simple, we suggest that there are at least three possible interrelated factors influencing this dual situation.

As presented in Table A2 (see Annex), the formation of two environments at the intrametropolitan scale (that is, more and less favourable places to capitalise on externalities from neighbouring cities) is conditioned partly by the situation in 2001 in terms of the concentration of qualified employment, the presence of establishments related to the knowledge economy and the presence of premises (e.g. office, commercial, industries). In particular, the results of the correlation analyses show interesting conclusions (see Table A2):

- On the one hand, a moderate correlation exists between the concentration of KE workers and cities that have already concentrated a certain highly skilled labour force (LC_occu) and KE activities (LC_act). A moderate correlation also exists between the concentration of KE workers and the existence of office spaces in 2001. No significant correlation is identified between the concentration of KE workers and diversity in the type of retail space and facilities in 2001 (I_shannon). These correlations can also be found when looking at KE in detail (PKIBS, TKIBS and C&C and OTHER services). Only HTI services show a particularly different pattern. In this case, a negative correlation is found

between the number of HTI workers and places that concentrated a certain number of cultural facilities in 2001.

- On the other hand, although a moderate correlation exists between the concentration of KE companies and cities that already concentrated KE activities (LC_act) and office spaces (LC_office) in 2001, the correlation with the concentration of the qualified labour force in 2001 is weak. No significant differences exist when looking in detail at the different types of KE services. Only TKIBs and C&C companies show a moderate correlation with the concentration of highly skilled workers in 2001. This is also significant for HTI firms, which – as expected – tended to concentrate in places with a lower concentration of cultural facilities in 2001 (negative correlation between the two variables).

All this confirms our third working hypothesis, that states that city trajectories (path dependence) influence the current concentration of KE.

5. Discussion

The analyses carried out in this work aims to analyse and assess the main casual mechanisms of agglomeration economies that have an influence on the spatial distribution of KE at the intrametropolitan scale. This paper pays special attention to borrowed size, the role of industrial diversity and specialisation and path dependence.

This study shows that the growth and diffusion of the KE benefit from the multicentric system in terms of agglomeration economies and the functional interactions between neighbouring nodes (borrowed size). In particular, for the Madrid Multicentric Urban Region, we verify what has been previously concluded for other main metropolitan areas: the role of city size and urban hierarchy in attracting knowledge-based activities. The centre of this metropolitan area, Madrid, exerts a key role in the concentration of the KE, accounting for more than 50% of the entire

urban region. However, other small and medium-sized cities (those centres over 10,000 inhabitants) contain important shares of the KE, suggesting the multicentric spatial character of the KE. In this sense, the borrowed-size effect amplifies the benefits of sharing (linkages between input suppliers and final producers), matching (labour market interaction) and learning (learning spillovers) from the networks built with surrounding cities (what Boix and Trullen (2007) called 'city network externalities').

Nevertheless, as expected, not all of the areas in the urban region function in the same way. The KE is located and grows in different ways within the metropolitan area (Giuliano et al., 2019). In this regard, we identify factors that influence the KE's spatial patterns, growth and dynamism and specialisation and/or diversity.

- First, the role of the distance to Madrid remains key in the KE concentration and dynamism. In general, close proximity to the main city is desirable for KE services. This finding accords with Polèse and Shearmur (2006), who refer to 'borrowed agglomeration economies' and note that resulting externalities occur within a one-hour travel time distance from a major city. In particular, the results of the correlation analysis for the Madrid urban region show that, during the post-crisis period (2012-2017), proximity to the capital reinforced the effect on innovation and learning processes, creation of networks and cooperation between public and private agents. However, this finding does not hold for certain KE activities, such as OTHER activities, related to education, health or defence activities, which do not follow a strict economic rationale but are related to political and governmental decisions to achieve an equilibrium in the population and facilities within the territory (Méndez and Tebar, 2011).
- Second, looking closely at each of the 71 centres within the Madrid urban region, we observe a disconnection between cities' demographic size and function. According to Meijers, Burger and Hoogerbrugge (2015), the rise of 'city network economies' leads

to processes of borrowed size and the rise of agglomeration shadows. In this vein, considering the rank-size rule (in terms of both demographic and functional sizes) for the Madrid urban region makes it possible to distinguish two different situations (see Figure 6):

(a) negative externalities (or agglomeration shadows) in cities that exhibit lower levels of urban functions than other areas with similar or larger demographic sizes, a situation that occurs mainly in the east and south of the Madrid urban region; and

(b) positive externalities (or knowledge spillovers) in cities that exhibit levels of urban functions more typical of larger cities (because of the benefits associated with networks of neighbouring cities), a situation that occurs mainly in the west and north of the Madrid urban region.

Insert Figure 6 here

- Third, unlike traditional studies, which explored whether specialisation or diversity drives growth and innovation, and according to van Oort (2015), it can be concluded that neither processes are exclusive and that both characterise the Madrid intrametropolitan area at different scales. On the one hand, the coexistence and diversity of functions within the urban region can be determined at the local scale: centres do not specialise in a single type of KE service. On the other hand, proximity to Madrid seems to influence specialisation and diversity processes at the intrametropolitan scale: whereas specialisation processes (Marshall-Arrow-Romer, or MAR, externalities; Glaeser et al. (1992) are identified within the first and second metropolitan rings (e.g. cluster 2 cities tend to specialise in PKIBS, TKIBS, C&C and HTI services and cluster 3 cities in HTI and T-KIBS services), they tend to decline toward the periphery of the Madrid urban region (e.g. cluster 1 cities in which all KE services have a similar

weight/proportion in the economy), with the diversity processes (Jacobs' externalities; Glaeser et al. (1992)) becoming more evident. In addition to the influence of the distance from Madrid, the spatial pattern of the cluster follows the radioconcentric distribution of the motorway system. In terms of KE workers, it can be concluded that a diverse, qualified labour force is distributed throughout the Madrid urban region. In this case, compared with the distribution of KE companies, the specialisation process is much less clear.

- Fourth, in the uneven distribution of the KE at the intrametropolitan scale, we observe that *history matters* and that those municipalities that in the 1980s and 1990s concentrated certain tertiary activities, cultural and educational amenities and qualified workers subsequently favoured the location of KE services. In other words, the spatial evolution of new technologies, innovations and knowledge spillovers (creation versus adoption) is related to, among other things, a path-dependence process (Polèse and Shearmur, 2006). The analyses developed in this paper show that, in 2001, KE workers tend to be located in cities that already have concentrations of certain highly skilled labour forces, KE activities, and office space. However, diversity in the type of retail space and facilities in 2001 does not seem to influence the concentration of KE workers. Similarly, KE companies tend to be located in cities that already had concentrated KE activities and office space in the past but are not influenced by the previous presence of highly skilled labour forces. Finally, cities with traditional concentrations of cultural facilities are less attractive in which HTI firms and workers could locate.

  Notably, the spatial clusters obtained in the analyses are in accordance with the traditional characterisations of the Madrid urban region. As noted by Méndez and Tebar (2011), Méndez y Sánchez Moral (2011) and Sánchez-Moral et al. (2019), since the 1980s, the North and West Madrilenian corridors have benefited from an important

public and private investments set aside for universities and private education institutions, financial campuses, private health facilities, technology parks and others. Conversely, the East and South corridors have specialised in less innovative and more polluting industries as the investment (mainly private) set aside to foster the expansion of the KE that is less significant than for the North and West corridors.

Moreover, we conclude that the KE distribution depends on the quality of the functions contained by a city derived from the spatial division of labour in the KE. The nature of the activities conducted within the firm and their positions within the global value chain influence the skills and opportunities for the labour force and the likely value that will be created and retained within a region. Besides, Historic Administrative Cities (HACs) around Madrid play an important role in the concentration and expansion of the KE (see Solís et al., 2015; Romero, 2019). Although these nodes are characterised by the absence of neighbouring cities and surrounded by a rural hinterland, they have benefited from the rescaling and decentralisation processes toward the regional scale. This is the case for the regional capital city of Toledo and provincial capital cities such as Ávila, Segovia, Cuenca and Guadalajara. In these cases, the concentration of the KE is less associated with a borrowed-size process and is more closely linked to an institutional function assigned by the state.

6. Conclusions

This paper contributes to science with a new, comprehensive framework to understand the spatial distribution and nature of the KE based on three mechanisms until now studied separately. Concretely, it focuses on: (1) the interaction effects of proximity derived from the agglomeration economies and borrowed size of KE, (2) the complementarity between the specialisation and diversity of the KE at the city and metropolitan levels, and (3) the impact of city trajectories over time on the current concentration and growth of the KE. The conclusions

derived from this study have also various practical implications for policymakers to take into account not only strategies (and investment) to coordinate land availability, worker training, connections between research centres and companies and amenities but also strategies to coordinate with the surrounding municipalities (e.g. in terms of mobility or joint public and private projects). To achieve this paper's aim (to shed light on the intrametropolitan spatial localisation of the KE), we focused on the Madrid urban area, which is a good example of a multicore urban region with a traditionally strong metropolis. Hence, the conclusions can be extrapolated to other similar multicentric metropolitan areas.

Although we are now fully in the information era, we have concluded that the KE tends to be located at multicore or multimode regional configurations. Our study confirms that the KE in the Madrid urban region is arranged in the metropolis of Madrid and the surrounding centres (small and medium-sized cites). Corroborating our first working hypothesis, we observe that – as in other urban regions (Giuliano et al., 2019) – the growth and location of the KE are positively influenced by the size of each city, the size of the surrounding cities (borrowed size) and the proximity to the largest city (in our study case, Madrid). The borrowed size and proximity to Madrid reveal the importance of geographical proximity as a mechanism for knowledge spillovers, the linkages between input suppliers and final producers and labour market interactions. These trends – far from declining – have continued and have been reinforced in the post-crisis period (2012-2017). Clearly, the KE represents an expanding set of economic activities and is part of the structural change of the new economic era.

As derived from our analysis, we confirm our first hypothesis: agglomeration economies and borrowed size are two ways to accumulate – mutually reinforced – knowledge and spillovers. Despite this, we observed that the benefits of agglomeration derived from size, borrowed size and proximity to the main city are not the same in all of the cities of the metropolitan urban system. Unravelling the influencing factors is not easy. This paper shows that the nodes of the

metropolitan urban system are not homogeneous and, confirming our third working hypothesis, we affirm that the different capacities for the action of the agents and investments over time predetermine the location and growth of the KE. Thus, historic city dynamics matter. We find that the presence of a traditionally high concentration of qualified workers, the presence of services and commerce and investments in certain facilities positively influence the concentration of the KE. Following the crisis, cities with the highest density of these three features exhibit greater increases in workers and companies related to the KE.

Moreover, for the investigated period, 2012-2017, verifying our second working hypothesis, we conclude that both specialisation and diversity work together in the growth of the KE, although at different scales – local and metropolitan. This conclusion implies that clusters change in nature with the Third Industrial Revolution. A spatial (labour) division of the KE can be perceived. The analysis of the sectoral composition of the KE (KIBS, TKIBS, HTI, C&C and OTHER) reveals different degrees of intensity for certain sectors for some cities. This fact relates to Eriksson's finding that 'proximity increases the need to be located near different, but related, industries, whereas increased distance implies a stronger effect of intra-industry spillovers (2011:127). However, the closer a city is to Madrid, the larger its size (more than 100,000 inhabitants) and the greater its administrative role (being a provincial and/or regional capital city), the more specialisation it displays in certain sectors, as shown in the fourth section and Figure 4a.

Finally, from the public policy perspective, we observe the need to implement a new style of government at three levels. We need more comprehensive local planning, strategic agreements between neighbouring cities and integrated planning on a metropolitan scale to take advantage of four major themes: (a) qualification and training of a workforce (to train workers in competencies and skills for the changes); (b) well-distributed cultural and social facilities on urban and territorial scales; (c) strengthened coordination of business and of firms and

resources; and (d) modernising communication and telecommunications infrastructures and promoting sustainable modes of transport on an urban scale and between neighbouring cities.

To conclude, this study has opened up areas for future research. First, one of the main drawbacks of our analysis of diversity and/or specialisation of the KE is the absence of a statistic to distinguish different firm-specific routines (or tasks). Future research should fill this gap, enabling the determination of (1) the presence of similarity, relatedness and unrelatedness among firms in the same city or in neighbouring cities; (2) knowledge spillovers and (3) the role of place-specific institutions. The second area of research would be an analysis and comparison of the evolution of the KE in cases in which there are and are not plans with neighbouring cities. The third area of research would be to assess how the KE influences social cohesion, per capita income and sustainability on a local scale.

7. References

Alonso, W. (1973). Urban zero population growth. *Daedalus* 102: 191–206

Boix, R. & Trullen, J. (2007). Knowledge, networks of cities and growth in a regional urban system. *Papers in Regional Science* 86: 551–574

Burguer, M.J., Meijers, E.J., Hoogerbrugge, M.M. & Masip, J. (2015) Borrowed Size, Agglomeration Shadows and Cultural Amenities in North-West Europe, *European Planning Studies*, 23:6, 1090-1109,

Camacho-Ballesta, J., Melikhova, Y., & Hernández-Peinado, M. (2013). Localization of business services in European regions: large urban areas stand out. European Planning Studies 22 (10), pp. 2094-2115.

Camagni, R., Capello, R. & Caragliu, A. (2015a). Static vs. dynamic agglomeration economies. Spatial context and structural evolution behind urban growth. *Papers in Regional Science*, 95 (1): 133-159.

Camagni, R., Capello, R. & Caragliu, A. (2015b). The rise of second-rank cities: what role for agglomeration economies?. *European Planning Studies* 23 (6):1-21.

Coffey, W., & Shearmur, R. (1997). The growth and location of high order services in the Canadian Urban System, 1971–1991. The Professional Geographer, 49, 404–418.

Combes, P. and Gobillon, L. (2015) The empirics of agglomeration economies. Duranton, G. Henderson, V. & Strange, W. (ed.) *Handbook of Regional and Urban Economics*, pp. 247-348, Elsevier.

Chica, E. (2016) Spatial clustering of knowledge-based industries in the Helsinki Metropolitan Area. *Regional Studies, Regional Science*, 3(1), 321-329.

Chong, S., Bahrami, M., Che, H., Balcisoy, S-. Bozkaya, B. & Pentland, A. (2020) "Economic outcomes predicted by diversity in cities", *EPJ Data Science*, 9, 17, 1-19.

Henderson, V. and Strange, W. (eds) *Handbook of Regional and Urban Economics*, 247-348.

Crescenzi, R. Iammarino, S., Joramoashvili, C., Rodríguez-Pose, A. & Storper, M. (2019) The geography of innovation: local hotspots and global innovation networks. Economic Research Working Paper. 57. WIPO.

Dima, A. M., Begu, L, Vasilescu, M. D. & Maassen, M. A. (2018) "The relationship between the Knowledge Economy and Global Competitiveness in the European Union. *Sustainability*, 10, 1-15.

Duranton, G., & Puga, D. (2000). Diversity and specialisation in cities: why, where and when does it matter? Urban Studies, 37, 533–555.

Eriksson, R. H. (2011). Localized spillovers and knowledge flows: how does proximity influence the performance of plants. *Economic Geography* 87 (2): 127-152.

Escolano-Utrilla, S., & Escalona-Orcao, A. I. (2017). Especialización, concentración y aglomeración espacial de los servicios intensivos en conocimiento en España. *Documents d'Anàlisi Geogràfica* 63 (1): 55-80.

Florida, R (2002) The rise of the creative class: and how it's transforming work, leisure, community and everyday life. Basic Books, New York

Gallego, J., & Maroto, A. (2013). The specialization in knowledge-intensive business services (KIBS) across Europe: permanent co-localization to debate. Regional Studies. doi:10.1080/00343404.2013.799762

Giuliano, G., Kang, S & Yuan, Q. (2019). Agglomeration economies and evolving urban form. *The Annals of Regions Science*. https://doi.org/10.1007/s00168-019-00957-4

Glaeser. E., Kallal, H., Scheinkman, J. A., & Shleifer, A. (1992) Growth in cities. *Journal of Political Economy*, 100, 6, 1126-1152.

Glaeser, E. (2011). *Triumph of the city: how our greatest invention makes us richer, smarter, greener, healthier, and happier*. New York, NY: Penguin Press

Hall, P. and Pain, K. (2006). *The polycentric metropolis. Learning from mega-city regions in Europe*. London: Earthscan.

Hamidi, S. & Zandiatashbar, A. (2018) Does urban form matter for innovation productivity? A national multilevel study of the association between neighborhood innovation capacity and urban sprawl. *Urban Studies*. https://doi.org/10.1177/0042098018767002

Harrison, B., Kelley, M.R., & Gant, J. (1996) Specialization Versus Diversity in Local Economies: The Implications for Innovative Private-Sector Behavior. *Cityscape* 2 (2): 61-93

Hecker, D. E. (2005). High-Tech Employment: a NAICS-based update. *Monthly Labor Review*, July, 57-72.

Henderson, V. J. (2010). Cities and development. *Journal of Regional Science* 50: 515–540

Henning, M., Stam, E., & Wenting, R. (2013). Path Dependence Research in Regional Economic Development: Cacophony or Knowledge Accumulation? *Regional Studies*, 47 (8): 1348–1362.

Hesmondhalgh, D. & Pratt, A. C. (2005). Cultural industries and cultural policy. *International Journal of Cultural Policy* 11 (1): 1-14.

Kemeny, T. & Storper, M. (2014). Is specialization good for regional economic development? *Regional Studies* 49:1003–1018.

Kijek, A. & Kijek, T. (2019) Knowledge spillovers: an evidence from the european regions. *Journal of Open Innovation. Technology, Market and Complexity*, 5, 68. https://doi.org/10.3390/joitmc5030068

Knieling, J, Othengrafen, F. & Vladova, G. (2016). Cities in crisis: setting the scene for reflecting urban and regional features in times of austerity. In Knieling, J. and Otherngrafen, F. (2016) Cities in crisis. Socio-spatial impacts of the economic crisis in Southern European cities. London: Routledge.

Lambooy, J. G. (1998). *Economies of agglomeration and spatial development: cities in the era of the knowledge economy*. Inaugural lecture University of Utrecht – 2 December 1998.

Meijers, E. & Burger, M. (2010). Spatial structure and productivity in US metropolitan areas. *Environment and Planning A* 42: 1383–1402.

Meijers, E. & Burger, M. (2015). Stretching the concept of borrowed-size. *Urban Studies* 54 (1): 269-291.

Meijers, E., Burger, M. & Hoogerbrugge, M. (2015). Borrowing size in networks of cities: city size, network connectivity and metropolitan functions in Europe. *Papers in Regional Science* 95 (1): 181-199.

Méndez, R. & Tebar, J. (2011). El mapa de la economía del conocimiento en la región metropolitana de Madrid. *Anales de Geografía* 31 (2):139-161.

Méndez, R., y Sánchez-Moral, S. (2011). Spanish cities in the knowledge economy: Theoretical debates and empirical evidence. *European Urban and Regional Studies*, 18 (2), 136–155.

Miles, N. Kastrinos, K. Flanagan, R. Bilderbeek, P. Den Hertog &W. Huntik, (1995) Knowledge intensive business services: Users, carriers and sources of innovation. European innovation monitoring system (EIMS), 15, European Commission, Brussels (1995).

Miles, I. (2008). Patterns of innovation in service industries. *IBM System Journal*, 47 (1): 115-128.

Mitchell. W. J. (1996) *City of bits: space, place and the infobahn*. MIT Press, Boston

Paci, R. and Usai, S. (2000) The Role of Specialisation and Diversity Externalities in the Agglomeration of Innovative Activities. *Rivista italiana degli economisti* 2, 237-268.

Phelps, N., Fallon R., & Williams, C. (2001). Small firms, borrowed size and the urban-rural shift. *Regional Studies* 35: 613–624.

Pierson, P. (2000). Increasing returns, path dependence and the study of politics. *American Political Science Review*, 94-2, pp. 251-267.

Pino, R. & Ortega, A. M. (2018) Regional innovation systemas: Systematic literature review and recommendations for future research. *Cogent Business and Maganegment*, 5, 1-17.

Polèse, M. & Shearmur, R. (2006). Growth and location of economic activity: The spatial dynamics of industries in Canada 1971–2001. *Growth and Change* 37(3): 362–395.

Porter, M. (1998). Clusters and the new economics of competition. *Harvard Business Review*. November-December, 77-90.

Powell, W. & Snellman, K. (2004) The knowledge economy. *Annu. Rev. Sociol* 30, 199–220.

Pumain, D., Pulus, F. & Vacchiani-Marcuzzo, C. (2009). Innovation cycles and urban dynamics". In D. Lane, D. Pumain, S. Van der Leew, & G. West (eds) *Complexity perspectives in innovation and social change* (pp. 237-260). Dordrecht: Springer.

Raspe, O. & van Oort, F. (2006) The knowledge economy and urban economic growth. European Planning Studies, 14, 9. DOI: 10.1080/09654310600933322.

Romero, V. (2019) The intrametropolitan geography of knowledge-intensive business services (KIBS): a comparative analysis of six european and U.S. City-Regions. *Economic Development Quarterly*, 1-17. DOI: 10.1177/0891242419875498

Sánchez-Moral, S., Díez-Pisonero, R., Gago-García, C- & Arellano-Espinar, A. (2019) Sectores Estratégicos en la Economía del Conocimiento y Desarrollo en la Ciudad de Madrid y su Región. *Revista de Estudios Andaluces*, 38: 144-161.

Sassen, S. (1991) *The global city: New York, London, Tokyo*. Princeton University Press.

Shearmur, R. (2012). The Geography of Intrametropolitan KIBS Innovation: Distinguishing Agglomeration Economies from Innovation Dynamics. *Urban Studie*s 49 (11): 2331–2356.

Shearmur, R. & Doloreux, D. (2008). Urban hierarchy or local milieu? High-order producer service and (or) knowledge-intensive business service location in Canada, 1991-2001. *Professional Geographer* 60: 333–355.

Solís, E., Ruiz-Apilanez, B. & Ureña, J. M. (2012). Transformación del sistema urbano-territorial en la región central de la España peninsular la emergencia de la región metropolitana policéntrica madrileña. *Scripta Nova: Revista electrónica de geografía y ciencias sociales* (16): 387-424.

Solís, E., Mohíno, I. & Ureña, J. M. (2015). Global Metropolitan-Regional Scale in Evolution: Metropolitan Intermediary Cities and Metropolitan Cities. *European Planning Studies* 23 (3): 568-596.

Storper, M. & Venables, A. J. (2003) *Buzz: Face-To-Face Contact and the Urban Economy.* Published by Centre for Economic Performance London School of Economics and Political Science. London.

Uppenberg, K. (2010) The knowledge economy in Europe. A review of the 2009 EIB Conference in Economics and Finance. European Investment Bank. Luxemburgo.

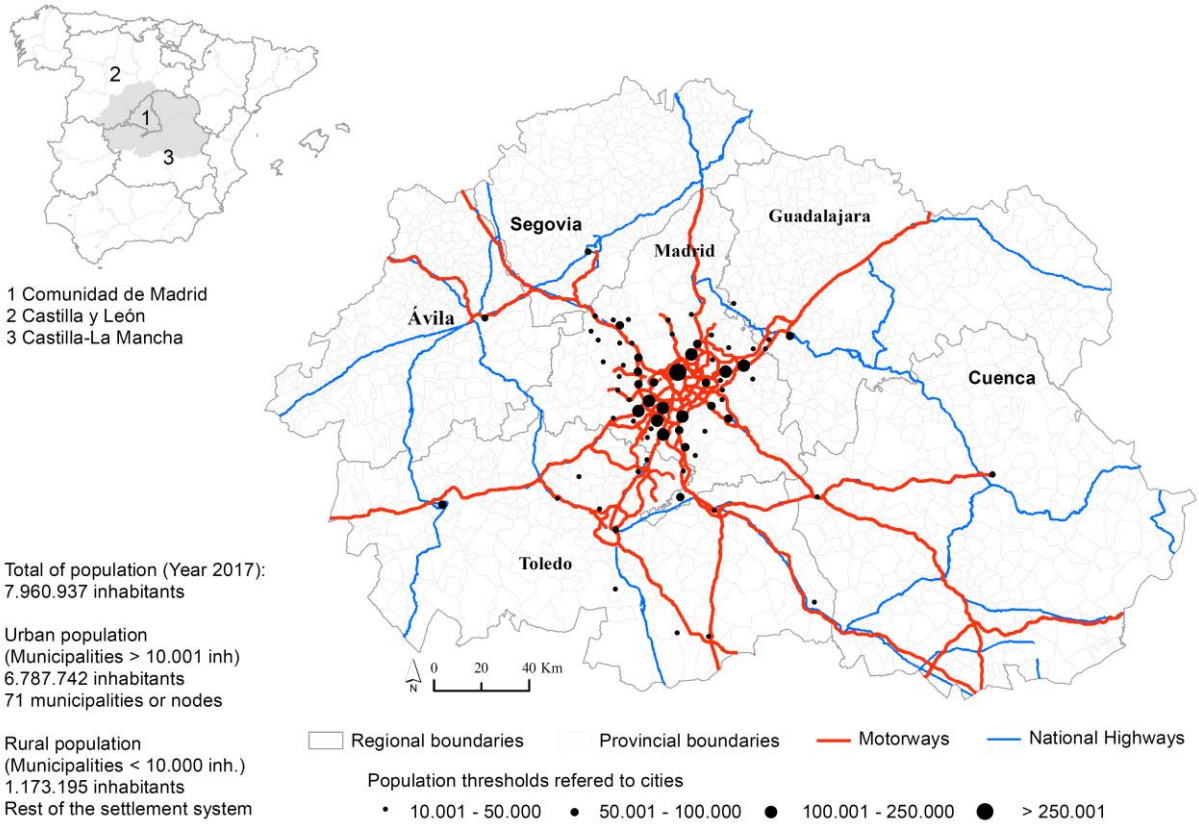
van Winden, W., van den Berg, L. & Pol, P. (2007). European Cities in the Knowledge Economy: Towards a Typology. *Urban Studies* 44 (3): 525–549.

van Oort, F. (2015). Unity in variety? Agglomeration economics beyond the specialization-diversity controversy. In Karlsson, C., Andersson, M., Norman, T. (Eds) *Handbook of Research Methods and Applications in Economic Geography.* Edgar: Cheltenham, UK and Northampton, MA

Volgmann, K. & Münter, A. (2018). Specialization of and complementarities between (new) knowledge clusters in the Frankfurt/Rhine-Main urban region. *Regional Studies* 5 (1): 125-148.

Ženka, J., Novotný, J., Slach, O. & Ivan, I. (2017) "Spatial Distribution of Knowledge-Intensive Business Services in a Small Post-Communist Economy" Journal of the Knowledge Economy 8(2), pp. 385-406

Figure 1. Madrid urban region



-Source: Authors

Figure 2. Variables to measure the effect of agglomeration and distance in the knowledge economy

Dependent variables
Years 2012 and 2017

Y1a (**KEwor):** Workers related to Knowledge Economy
Y1b (**KEcom):** Companies related to Knowledge Economy

Y2a (**P-KIBSwor**): Workers in P-KIBs
Y2b (**P-KIBScom):** Companies in P-KIBS

Y3a (**T-KIBSwor):** Workers in T-KIBS
Y3b (**T-KIBScom):** Companies in T-KIBS

Y4a (**HTIwor):** Workers in HTI
Y4b (**HTIcom):** Companies in HTI

Y5a (**C&Cwor):** Workers in C&C
Y5b (**C&Ccom):** Companies in C&C

Y6a (**OTHERwor):** Workers in OTHER
Y6b (**OTHERcom):** Companies in OTHER

Independent variables (territorial features)
Years 2012 and 2017

Suggested variables to measure city size and agglomeration effects:

X1 (**POP)**: Population size
X2 (**COM):** Total number of companies
X3 (**WOR):** Total number of workers

Suggested variables to measure the borrowed-size effects:

X4 (**COMbz):** Total number of companies in each municipality and in adjacent ones
X5 (**COMbzKE):** Total number of KE-companies in each municipality and in adjacent ones
X6 (**WORbz):** Total number of workers in each municipality and in adjacent ones
X7 (**WORbzKE):** Total number of KE-workers in each municipality and in adjacent ones

Suggested variables to measure the effect of proximity to Madrid:

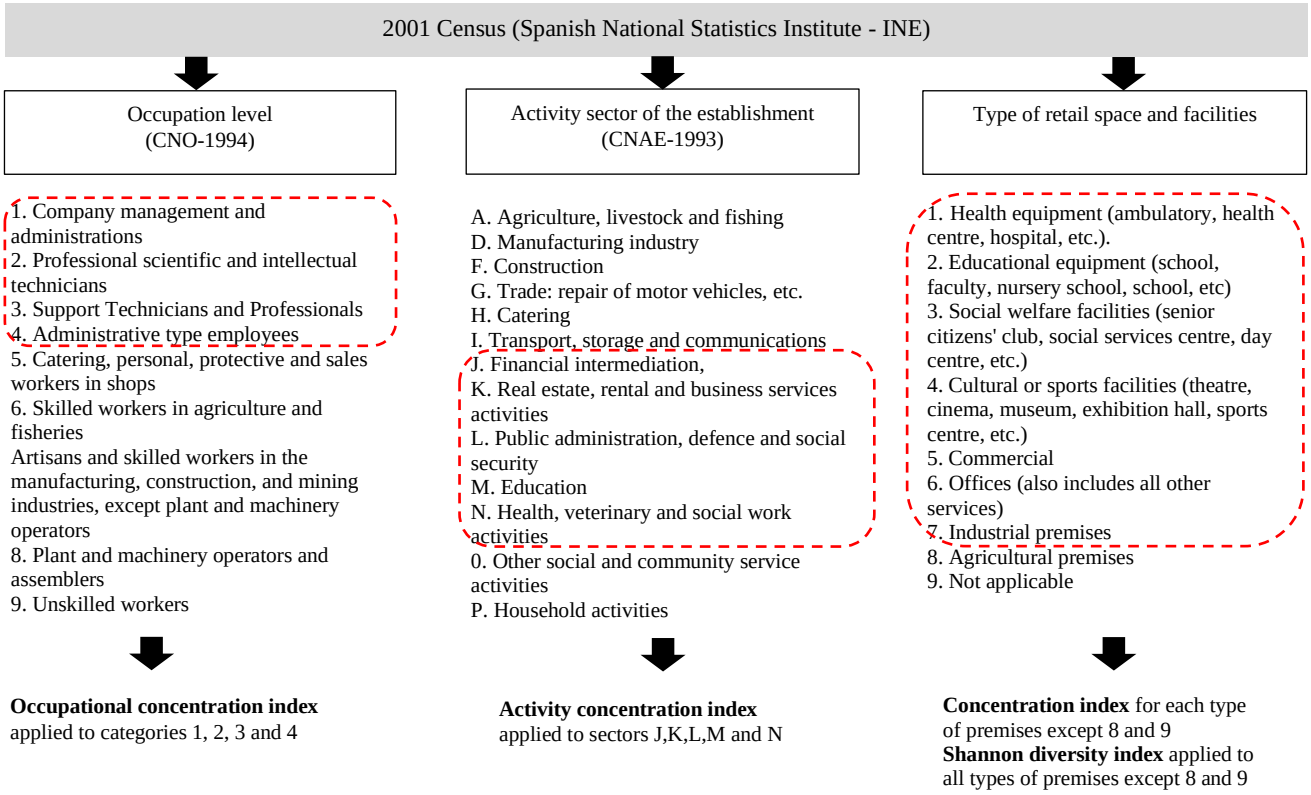
X8 (**DISMad):** Temporal distance (in minutes) to Madrid along the road network. (Source: National Center for Geographic information (CNIG). Calculated in ArcGis 10.3.1)

City Size
(localised economies & urbanised economies)

Borrowed Size
(neighbouring or adjacent cities, defined as municipalities sharing part of their boundaries)

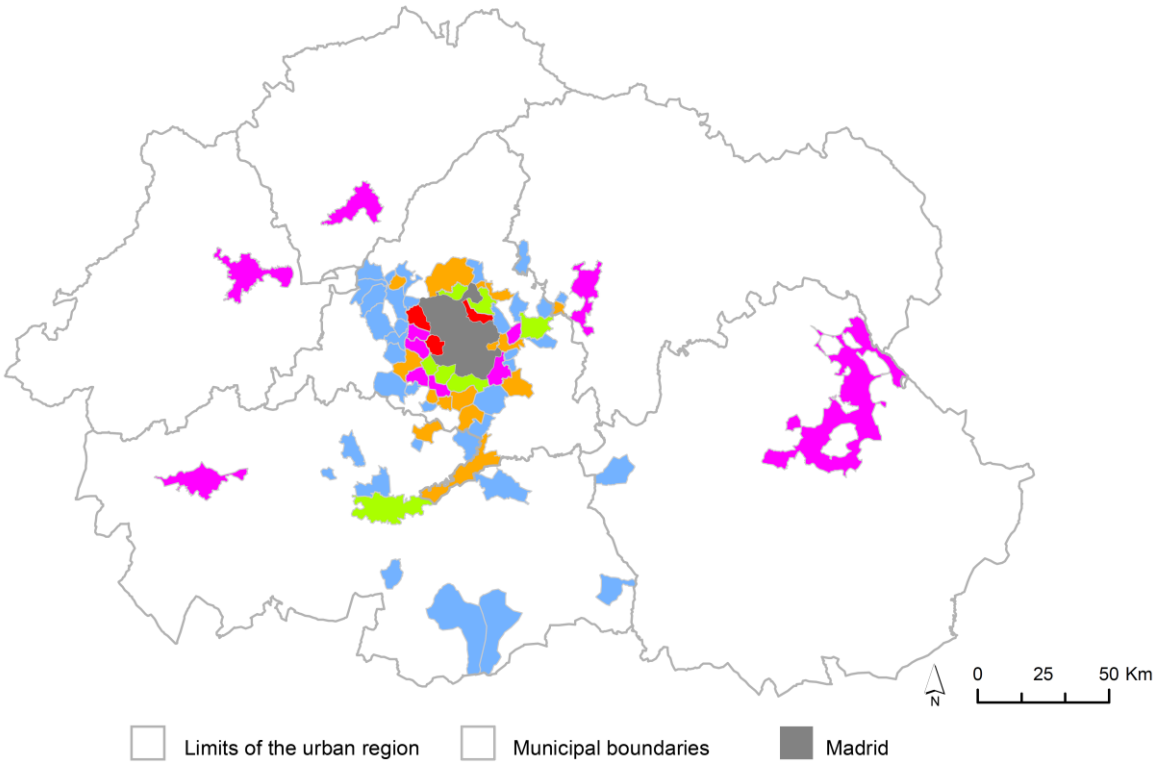
-Source: Authors

Figure 3. Variables (included in the 2001 Census) considered for the *path-dependence analysis*



-Source: Authors

Figure 4a. Clusters of centres in terms of concentration of KE companies in TKIBS, PKIBS, HTI, C&C and OTHERs

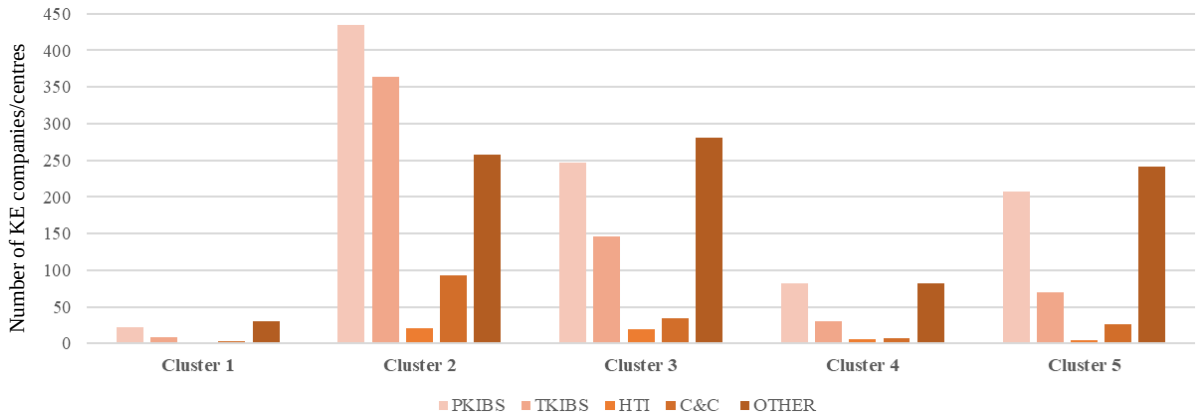


Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
36 centres	3 centres	7 centres	14 centres	11 centres
PKIBS	PKIBS	PKIBS	PKIBS	PKIBS
TKIBS	TKIBS	TKIBS	TKIBS	TKIBS
HTI	HTI	HTI	HTI	HTI
C&C	C&C	C&C	C&C	C&C
OTHER	OTHER	OTHER	OTHER	OTHER

Very High	Outliers
High	> Q3
Medium High	Q2-Q3
Medium Low	Q1-Q2
Low	< Q1

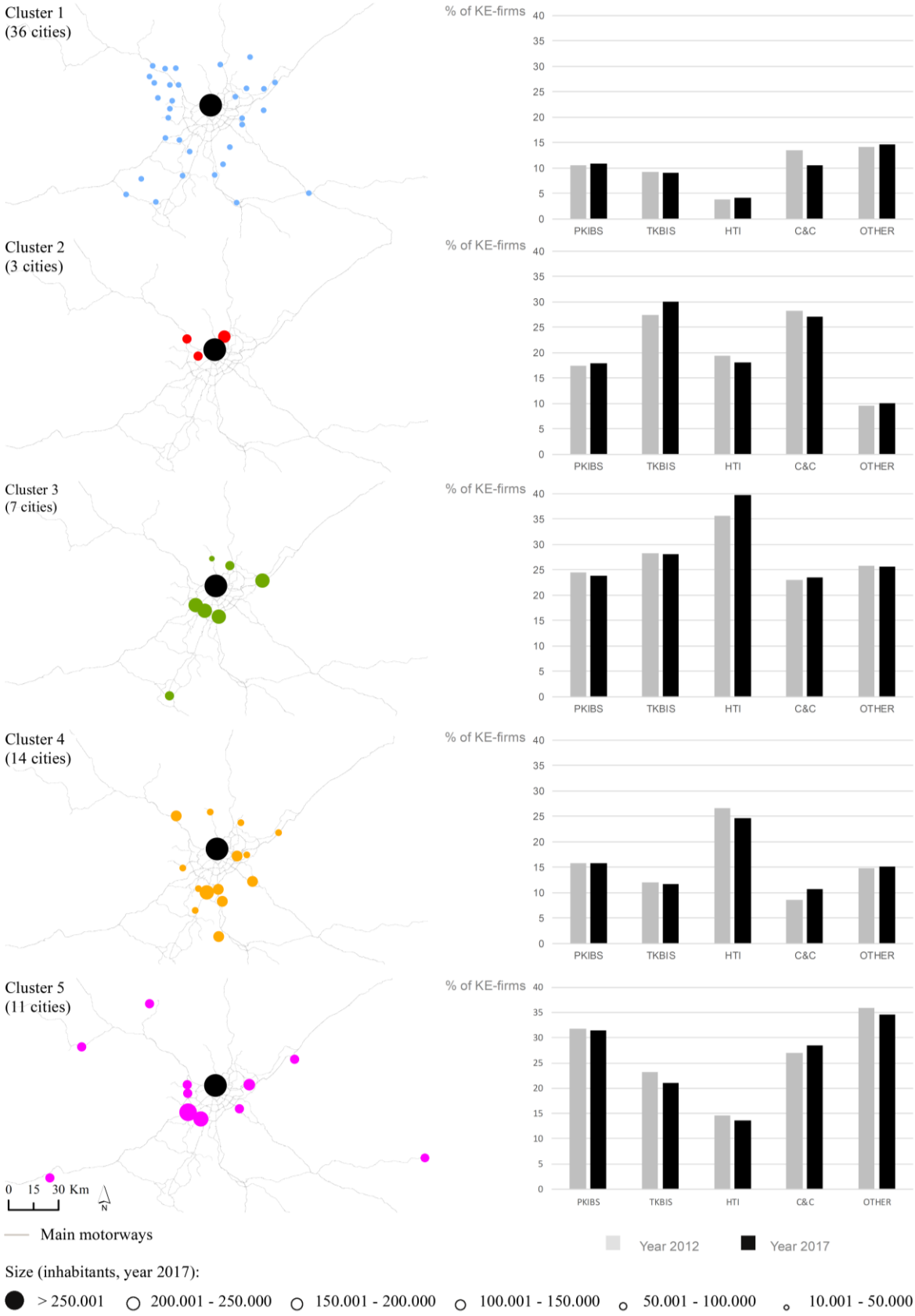
Source: Authors

Figure 4b. Ratio of number of KE companies (TKIBS, PKIBS, HTI, C&C and OTHERs) per number of centres of each cluster



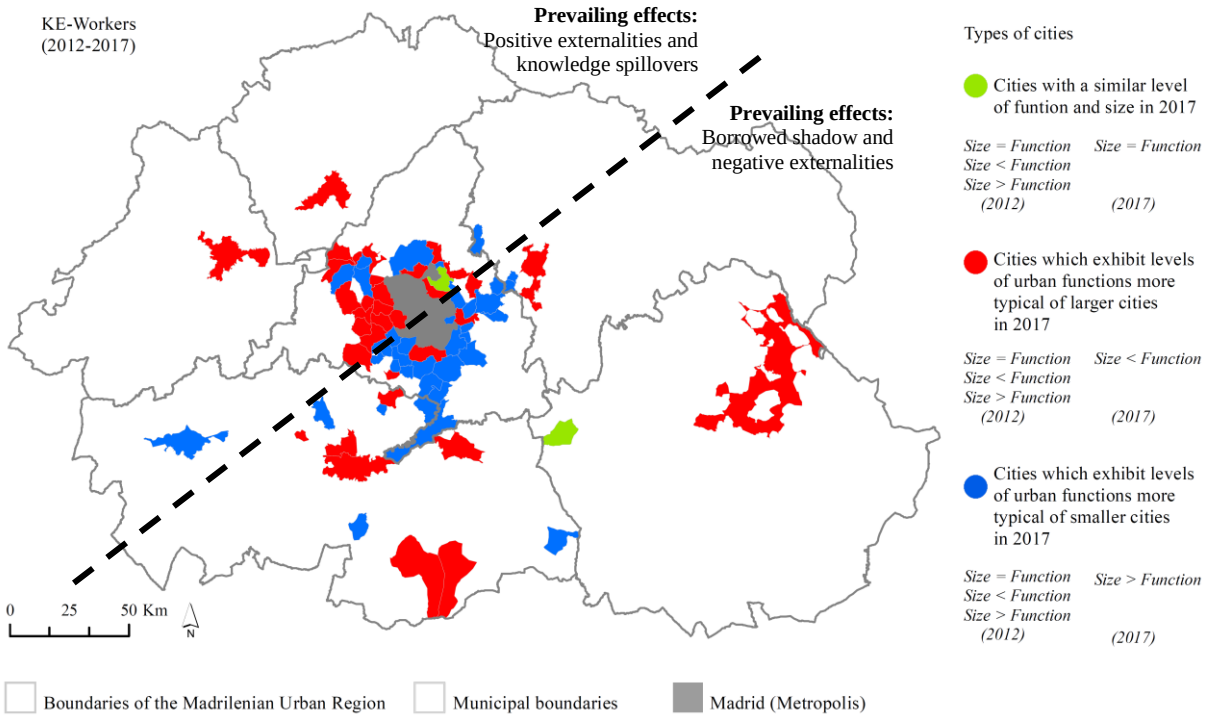
Source: Authors

Figure 5. Concentration of KE companies by cluster



-Source: Authors

Figure 6. Disconnection between size and function level



Note: Size is expressed in population, and function is expressed according to the number of KE workers.

-Source: Authors

Table 1. Evolution of workers and companies by economic sector between 2012 and 2017

	Urban system	Primary sector	Secondary sector	Tertiary sector	Total	Knowledge-based economy	% of KE (of the total)	% of KE (of the tertiary sector)
Number of companies	< 1,000 inhabs	341	-113	925	1,153	245	21.2	26.5
	1,001 - 5,000 inhabs	530	-529	946	947	292	30.8	30.9
	5,000 - 10,000 inhabs	242	-263	216	195	132	67.7	61.1
	10,000 - 50,000 inhabs	115	122	2.097	2.334	699	29.9	33.3
	50,001 - 250,000 inhabs	40	581	7,738	8,359	2,520	30.1	32.6
	> 250,001 inhabs (Madrid)	22	263	12,728	13,013	5,886	45.2	46.2
	Madrid urban region	1,290	61	24,650	26,001	9,774	37.6	39.7
Number of workers	< 1,000 inhabs	459	2,045	5,747	8,251	1,288	15.6	22.4
	1,001 - 5,000 inhabs	530	3,825	8,963	13,318	3,503	26.3	39.1
	5,000 - 10,000 inhabs	72	3,588	9,911	13,571	3,263	24.0	32.9
	10,000 - 50,000 inhabs	150	9,883	34,546	44,579	17,282	38.8	50.0
	50,001 - 250,000 inhabs	349	10,046	105,831	116,226	32,487	28.0	30.7
	> 250,001 inhabs (Madrid)	-663	-1,762	231,607	229,182	127,448	55.6	55.0
	Madrid urban region	897	27,625	396,605	425,127	185,271	43.6	46.7

Source: Authors, based on data from the Departments of Economic Affairs and Finances of Castilla-La Mancha, Castilla y León and Madrid autonomous regions.

Table 2. Percentage of companies and workers in KE (by type of activity)

	Companies (Year 2012)						Companies (Year 2017)					
Urban system	PKIBS	TKIBS	HTI	C&C	OTHER	Total of KE	PKIBS	TKIBS	HTI	C&C	OTHER	Total of KE
< 1,000 inhabs	0.3	0.3	0.2	0.5	9.9	3.6	0.5	0.4	0.3	0.4	9.4	3.5
1,001 - 5,000 inhabs	1.8	1.3	4.3	1.7	6.2	3.3	1.9	1.3	4.9	1.9	6.1	3.2
5,000 - 10,000 inhabs	2.1	2.0	3.6	2.1	4.1	2.8	1.9	1.7	4.4	1.7	3.9	2.5
10,000 - 50,000 inhabs	5.1	6.2	13.7	5.5	7.4	6.2	5.3	6.0	13.6	5.0	7.9	6.4
50,001 - 250,000 inhabs	23.7	25.6	41.8	21.0	28.8	25.8	23.5	25.2	41.2	23.6	29.0	25.8
> 250,001 inhabs (Madrid)	67.1	64.6	36.3	69.3	43.5	58.3	67.0	65.5	35.6	67.5	43.6	58.6
Madrid urban region	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	Workers (2012)						Workers (2017)					
Urban system	PKIBS	TKIBS	HTI	C&C	OTHER	Total of KE	PKIBS	TKIBS	HTI	C&C	OTHER	Total of KE
< 1,000 inhabs	0.1	0.1	0.2	0.1	0.9	0.5	0.1	0.1	0.0	0.1	1.0	0.5
1,001 - 5,000 inhabs	0.8	0.5	3.9	0.8	1.9	1.3	0.8	0.5	3.7	0.8	2.0	1.4
5,000 - 10,000 inhabs	0.9	0.7	0.7	1.0	2.1	1.4	0.9	0.7	0.9	1.0	2.2	1.5
10,000 - 50,000 inhabs	3.7	5.8	13.1	5.1	4.9	5.1	5.6	6.1	14.6	5.0	5.1	5.8
50,001 - 250,000 inhabs	22.0	24.6	62.7	28.3	32.6	29.3	22.5	22.5	61.1	28.8	29.8	27.6
> 250,001 inhabs (Madrid)	72.5	68.4	19.5	64.6	57.5	62.3	70.0	70.1	19.6	64.2	59.9	63.3
Madrid urban region	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Source: Authors, based on data from the Departments of Economic Affairs and Finances of Castilla-La Mancha, Castilla y León and Madrid autonomous regions.

Table 3. The effect of Madrid (the metropolis) on the spatial distribution of population, KE workers and KE companies in the urban system of the city-region

Travel time from Madrid (in minutes)	Number of cities	% of Firms		% of Workers		% of KE-Firms		% of KE-Workers	
		2012	2017	2012	2017	2012	2017	2012	2017
Madrid	1	60.1	59.8	59.2	59.1	64.5	64.5	64.4	65.5
< 20'	7	10.4	10.8	10.0	10.3	8.4	8.7	9.5	9.5
21 - 40'	43	20.9	21.5	22.5	22.3	17.6	18.0	17.8	17.1
41 - 60'	12	5.3	4.8	5.5	5.5	6.0	5.5	5.8	5.5
61 - 80'	5	2.2	2.0	1.9	1.8	2.5	2.2	1.6	1.5
80 - 100'	3	1.1	1.0	1.0	1.0	1.1	1.0	1.0	0.9
Total	71	331,720	355,426	2,846,793	3,236,780	47,012	56,117	1,034,853	1,212,070

Travel time from Madrid (in minutes)	Number of cities	Percentage of firms									
		PKIBS 2012	TKIBS 2012	HTI 2012	C&C 2012	OTHER 2012	PKIBS 2017	TKIBS 2017	HTI 2017	C&C 2017	OTHER 2017
Madrid	1	70.0	67.0	39.5	72.4	54.6	70.0	67.7	39.3	70.3	54.1
< 20 '	7	7.1	10.2	14.0	8.5	8.8	7.2	10.8	14.7	9.1	9.0
21 - 40 '	43	15.3	16.9	36.9	13.2	21.4	15.5	16.7	38.6	13.8	22.8
41 - 60 '	12	4.8	3.9	6.8	4.1	9.2	4.7	3.2	5.4	4.5	8.4
61 - 80 '	5	1.9	1.4	1.7	1.1	4.3	1.7	1.1	1.1	1.4	3.9
80 - 100 '	3	0.9	0.6	1.1	0.7	1.8	0.9	0.4	0.9	0.8	1.7
Total	71	19,732	9,208	529	3,159	14,384	24,148	11,257	557	3,453	16,702

Travel time from Madrid (in minutes)	Number of cities	Percentage of workers									
		PKIBS 2012	TKIBS 2012	HTI 2012	C&C 2012	OTHER 2012	PKIBS 2017	TKIBS 2017	HTI 2017	C&C 2017	OTHER 2017
Madrid	1	73.6	69.2	20.5	65.9	60.0	71.2	71.0	20.6	65.4	62.7
< 20 '	7	6.6	11.4	22.1	17.4	8.1	7.4	11.7	24.9	16.9	7.4
21 - 40 '	43	14.0	17.4	51.8	13.1	17.7	16.5	15.5	48.6	14.1	16.0
41 - 60 '	12	3.6	1.3	5.5	2.7	9.3	3.1	1.2	5.9	2.7	9.0
61 - 80 '	5	1.1	0.4	0.1	0.4	2.5	0.9	0.3	0.0	0.5	2.4
80 - 100 '	3	1.1	0.4	0.1	0.4	2.5	0.9	0.3	0.0	0.5	2.4
Total	71	239,755	229,847	36,050	57,424	476,359	278,249	274,982	40,850	62,414	560,636

Source: authors

ANNEX - SUMMARY OF THE SPATIAL CORRELATION ANALYSES

Table A1. Types of KE-workers and KE-companies and independent variables

2012												
Independent variables (Workers)	KEwor		P-KIBS		T-KIBS		HTI		C&C		OTHER	
	Rho	Sig.	Rho	Sig.	Rho	Sig.	Rho	Sig.	Rho	Sig.	Rho	Sig.
POP	,929**	,000	,876**	,000	,842**	,000	,685**	,000	,741**	,000	,899**	,000
COM	,974**	000	,954**	,000	,921**	,000	,728**	,000	,850**	,000	,922**	,000
WOR	,925**	,000	,891**	,000	,867**	,000	,767**	,000	,786**	,000	,881**	,000
COMbz	,602**	,000	,585**	,000	,742**	,000	,600**	,000	,717**	,000	,564**	,000
WORbz	,601**	,000	,582**	,000	,734**	,000	,652**	,000	,667**	,000	,565**	,000
COMbzKE	,649**	,000	,634**	,000	,776**	,000	,618**	,000	,750**	,000	,615**	,000
WORbzKE	,640**	,000	,633**	,000	,773**	,000	,604**	,000	,760**	,000	,610**	,000
DISMad	-,470**	,000	-,447**	,000	-,602**	,000	-,468**	,000	-,558**	,000	-,439**	,000

2017												
Independent variables (Workers)	KEwor		P-KIBS		T-KIBS		HTI		C&C		OTHER	
	Rho	Sig.	Rho	Sig.	Rho	Sig.	Rho	Sig.	Rho	Sig.	Rho	Sig.
POP	,935**	,000	,876**	,000	,868**	,000	,695**	,000	,832**	,000	,890**	,000
COM	,975**	,000	,935**	,000	,924**	,000	,752**	,000	,906**	,000	,910**	,000
WOR	,919**	,000	,876**	,000	,843**	,000	,757**	,000	,835**	,000	,849**	,000
COMbz	,630**	,000	,627**	,000	,755**	,000	,632**	,000	,727**	,000	,547**	,000
WORbz	,638**	,000	,627**	,000	,747**	,000	,652**	,000	,713**	,000	,561**	,000
COMbzKE	,671**	,000	,665**	,000	,781**	,000	,643**	,000	,753**	,000	,598**	,000
WORbzKE	,610**	,000	,614**	,000	,732**	,000	,582**	,000	,706**	,000	,550**	,000
DISMad	-,502**	,000	-,504**	,000	-,626**	,000	-,503**	,000	-,591**	,000	-,402**	,000

** Statistically significant at the 0.01 level (bilateral)

2012												
Independent variables (Companies)	KEcom		P-KIBS		T-KIBS		HTI		C&C		OTHER	
	Rho	Sig.	Rho	Sig.	Rho	Sig.	Rho	Sig.	Rho	Sig.	Rho	Sig.
POP	,906**	,000	,918**	,000	,880**	,000	,702**	,000	,714**	,000	,922**	,000
COM	,957**	,000	,965**	,000	,947**	,000	,726**	,000	,830**	,000	,932**	,000
WOR	,925**	,000	,921**	,000	,899**	,000	,784**	,000	,763**	,000	,895**	,000
COMbz	,650**	,000	,575**	,000	,664**	,000	,526**	,000	,593**	,000	,553**	,000
WORbz	,693**	,000	,577**	,000	,669**	,000	,579**	,000	,560**	,000	,559**	,000
COMbzKE	,693**	,000	,619**	,000	,703**	,000	,542**	,000	,637**	,000	,611**	,000
WORbzKE	,693**	,000	,602**	,000	,705**	,000	,517**	,000	,654**	,000	,599**	,000
DISMad	-,523**	,000	-,451**	,000	-,538**	,000	-,418**	,000	-,471**	,000	-,403**	,000

2017												
Independent variables (Companies)	KEcom		P-KIBS		T-KIBS		HTI		C&C		OTHER	
	Rho	Sig.	Rho	Sig.	Rho	Sig.	Rho	Sig.	Rho	Sig.	Rho	Sig.
POP	,900**	,000	,921**	,000	,892**	,000	,716**	,000	,820**	,000	,929**	,000
COM	,949**	,000	,970**	,000	,951**	,000	,762**	,000	,921**	,000	,942**	,000
WOR	,894**	,000	,912**	,000	,889**	,000	,803**	,000	,861**	,000	,899**	,000
COMbz	,646**	,000	,605**	,000	,703**	,000	,600**	,000	,640**	,000	,569**	,000
WORbz	,650**	,000	,614**	,000	,708**	,000	,626**	,000	,641**	,000	,584**	,000
COMbzKE	,685**	,000	,645**	,000	,738**	,000	,616**	,000	,677**	,000	,618**	,000
WORbzKE	,635**	,000	,581**	,000	,684**	,000	,554**	,000	,629**	,000	,558**	,000
DISMad	-,511**	,000	-,477**	,000	-,574**	,000	-,490**	,000	-,513**	,000	-,428**	,000

** Statistically significant at the 0.01 level (bilateral)
* Statistically significant at the 0.05 level (bilateral)

-Source: Authors

Table A2. Correlation analyses of path dependence effect

Independent variables (workers)_2001	2012											
	KEwor		P-KIBS		T-KIBS		HTI		C&C		OTHER	
	Rho	Sig.	Rho	Sig.	Rho	Sig.	Rho	Sig.	Rho	Sig.	Rho	Sig.
LC_occu	,355**	0,002	,402**	,000	,466**	,000	,131	,274	,529**	,000	,259*	,028
LC_act	,495**	0,000	,516**	,000	,500**	,000	,117	,327	,580**	,000	,460**	,000
I_shannon	0,260	0,833	,0720	,550	,101	,397	,096	,423	,080	,505	-,017	,888
LC_Health Facilities	0,228	0,054	,291*	,013	,221	,062	,000	,998	,221	,062	,217	,068
LC_Education Facilities	0,223	0,060	,278*	,018	,281*	,017	,181	,128	,210	,076	,176	,140
LC_Social Welfare Fac.	-0,124	0,300	-,103	,389	-,195	,101	-,252*	,033	-,071	,554	-,070	,559
LC_Cultural Facilities.	-0,182	0,125	-,105	,379	-,146	,222	-,345**	,003	-,081	,501	-,182	,127
LC_Commercial	0,220	0,064	,275*	,019	,134	,261	,043	,723	,100	,404	,262*	,026
LC_Office	,363**	0,002	,339**	,001	,351**	,002	,094	,431	,314**	,007	,355**	,002
LC_Industrial	-0,221	0,062	-,239*	,043	-,142	,233	,123	,304	-,193	,104	-,233*	,049
Independent variables (workers)_2001	**2017**											
	KEwor		P-KIBS		T-KIBS		HTI		C&C		OTHER	
	Rho	Sig.	Rho	Sig.	Rho	Sig.	Rho	Sig.	Rho	Sig.	Rho	Sig.
LC_occu	0,370**	0,001	,393**	,001	,471**	,000	,188	,133	,496**	,000	,267*	,024
LC_act	0,517**	0,000	,498**	,000	,498**	,000	,161	,176	,566**	,000	,480**	,000
I_shannon	0,062	0,606	,081	,501	,080	,505	,106	,375	,125	,296	,000	,998
LC_Health Facilities	0,256*	0,030	,264*	,025	,222	,061	,028	,815	,280*	,017	,241*	,041
LC_Education Facilities	0,251*	0,033	,266*	,024	,299*	,011	,222	,061	,263*	,025	,183	,123
LC_Social Welfare Fac.	-0,104	0,385	-,096	,423	-,202	,089	-,266	,056	-,0,75	,532	-,061	,611
LC_Cultural Facilities.	-0,164	0,169	-,121	,311	-,162	,174	-,333**	,004	-,074	,535	-,142	,235
LC_Commercial	0,234*	0,048	0,239*	,044	,174	,144	,096	,420	,185	,120	,284*	,016
LC_Office	0,388**	0,001	0,380**	,001	,319**	,006	,142	,235	,374**	,001	,362**	,002
LC_Industrial	-0,215	0,069	-,215	,070	-,150	,210	,076	,525	-,207	,082	-,229	,053

Independent variables (companies)_2001	2012											
	KEcom		P-KIBS		T-KIBS		HTI		C&C		OTHER	
	Rho	Sig.	Rho	Sig.	Rho	Sig.	Rho	Sig.	Rho	Sig.	Rho	Sig.
LC_occu	,289*	0,014	,235*	,047	,380**	,001	,035	,770	,478**	,000	,235*	,047
LC_act	,448**	0,000	,386**	,001	,453**	,000	,062	,606	,586**	,000	,440**	,000
I_shannon	0,07	0,557	,099	,408	,100	,402	,193	,104	,106	,374	,049	,686
LC_Health Facilities	,266*	0,024	,290*	,013	,223	,059	,078	,513	,291*	,013	,270*	,022
LC_Education Facilities	,233*	0,049	,229	,053	,276*	,019	,199	,094	,275*	,019	,210	,077
LC_Social Welfare Fac.	-0,102	0,393	-,119	,320	-,172	,148	-,232	,050	-,064	,593	-,061	,609
LC_Cultural Facilities.	-0,167	0,161	-,165	,165	-,150	,207	-,292*	,013	-,075	,533	-,148	,214
LC_Commercial	,241*	0,041	,218	,066	,190	,111	-,029	,808	,143	,232	,257*	,030
LC_Office	,392**	0,001	,379**	,001	,382**	,001	,139	,243	,396**	,001	,369**	,001
LC_Industrial	-0,188	0,114	-,147	,218	-,145	,224	,163	,171	-,245*	,038	-,214	,071
Independent variables (companies)_2001	**2017**											
	KEcom		P-KIBS		T-KIBS		HTI		C&C		OTHER	
	Rho	Sig.	Rho	Sig.	Rho	Sig.	Rho	Sig.	Rho	Sig.	Rho	Sig.
LC_occu	,290*	0,013	,253*	,032	,390**	,001	,085	,479	,435**	,000	,242*	,041
LC_act	,431**	0,000	,388**	,001	,442**	,000	,098	,411	,539**	,000	,423**	,000
I_shannon	0,075	0,529	,046	,702	,102	,392	,173	,145	,141	,237	,054	,654
LC_Health Facilities	,253*	0,032	,233*	,049	,220	,064	,077	,521	,274*	,020	,264*	,025
LC_Education Facilities	,244*	0,039	,224	,059	,295*	,012	,232	,050	,330**	,005	,221	,062
LC_Social Welfare Fac.	-0,137	0,251	-,163	,171	-,202	,088	-,253*	,032	-,093	,435	-,095	,427
LC_Cultural Facilities.	-0,164	0,169	-,194	,103	-,146	,221	-,306**	,009	-,121	,310	-,158	,186
LC_Commercial	,233*	0,049	,257*	,029	,177	,137	,004	,973	,207	,081	,235*	,047
LC_Office	,366**	0,002	,346**	,003	,355**	,002	,167	,162	,434**	,000	,343**	,003
LC_Industrial	-0,158	0,184	-,161	,176	-,117	,329	,136	,254	-,201	,090	-,176	,139

** Statistically significant at the 0.01 level (bilateral)
* Statistically significant at the 0.05 level (bilateral)

-Source: Authors