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Are organizational and economic proximity driving factors of scientific collaboration? Evidence from Spanish universities, 2001–2010

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Abstract
This paper aims to explore the effects that organizational and economic proximity have on scientific collaboration (SC) among Spanish universities, which are institutions in a peripheral country to EU-15. The methodology to address our research relies on data from a set of co-authored articles indexed in the Science Citation Index provided by Web of Science and published between 2001 and 2010 by 903 pairs of collaborating universities. This paper contributes to the existing literature in several ways. First, we aim to study how Spanish academic SC evolved in the period 2001–2010 in order to identify which universities were more prone to collaborate. Second, we analyse how collaboration across distance has evolved over time, considering two periods: 2001–2005 and 2006–2010. Finally, we put forward an econometric model to analyse how geographical, cognitive, institutional, social, organizational and economic proximity affect SC. Among other results, we find that differences in the size of the collaborating universities are not relevant to explaining academic SC, while disparities in ages and international vocation affect SC. With regard to economic proximity, differences in GDP are not relevant, while differences in financial funding suggest a stronger rate of collaboration among universities with different levels of funding. Building on our results, we provide some policy implications.

Keywords Scientific collaborations · Organizational proximity · Economic proximity · Proximity dimensions · Gravity equation

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Introduction

In line with the theories of endogenous growth, knowledge production and diffusion stimulates long-term development and economic growth (Romer 1986, 1990; Lucas 1988; Aghion and Howitt 1992, 1998). In this context, universities are a valuable source of new knowledge. Academic institutions play a relevant role in terms of their contribution to social, economic and technological development through the externalities that scientific knowledge generates and create economic conditions for higher levels of growth, employment and prosperity.

In this regard, collaborations play an extremely important role as a mechanism for the generation and diffusion of scientific knowledge. Scientific collaboration (SC) can be understood as an interaction process in which knowledge is related to skills, competences and resources, effective communication and exchange of ideas (Melin and Persson 1996; Katz and Martin 1997). Several papers have reviewed the literature on the reasons why SC improves the quality of research, facilitates the generation of knowledge, obtains complementarities in the use of resources and creates social networks of knowledge that favour knowledge diffusion (Katz and Martin 1997; Bozeman and Corley 2004; Adams et al. 2005; Sonnenwald 2007; Defazio et al. 2009; Franceschet and Costantini 2010).

Explaining the effects that proximity has on SC among universities is related to the advantages of agglomeration, given that the creation of knowledge results not only from the transfer of codified knowledge but also from tacit knowledge facilitated by personal interactions (Lundvall 1992). As previous literature claims (Boschma 2005; Knoben and Oerlemans 2006; Balland et al. 2015), proximity among economic actors allows access to relevant knowledge of a complementary nature, facilitating personal contacts based on trust and stable relationships.

This paper explores SC among Spanish universities using a proximity perspective as a framework. Focusing on SC in Spain is justified by two main reasons: First, we developed our analysis at the level of universities, but we do not have access to comparable data at international level. Second, Spain is a peripheral country located in the South of Europe, with lower level of R&D resources than EU-15 average. This peripheral feature makes it particularly interesting from a policy viewpoint. In doing so, we focus on the dynamics of the proximity dimensions in Spain to investigate factors encouraging national SC and to explore how proximity and knowledge evolve in the framework of a dynamic perspective (Torre and Gilly 2000; Balland et al. 2015).

This paper contributes to the existing literature in several ways. First, we aim to study how Spanish SC evolved in the period 2001–2010 in order to rank universities (top 10) in terms of academic activities (publications and collaborations). Second, we analyse how different dimensions of proximity evolved over time, considering two periods: 2001–2005 and 2006–2010. Finally, we provide a joint analysis of collaboration among Spanish universities to analyse different notions of proximity well-studied in the literature, namely, geographical, cognitive, institutional and social proximity, and paying special attention to organizational and economic proximity, as underexamined factors in the literature about university knowledge diffusion. In doing so, we contribute to the empirical evidence by providing an econometric analysis using data for the period 2006–2010[1] to validate the

[1] The period of time used in our econometric model is limited to 2006–2010 since we used collaborations in the preceding period, 2001–2005, as independent variable to assess previous relationships among academic actors (social proximity).

relevance of two core notions of proximity, organizational and economic factors at a national scale. We choose these core notions of proximity based on two reasons: (1) organizational proximity has been a well-studied factor in proximity literature trying to explain industry-university collaborations but not in academic collaboration among universities, and (2) economic proximity has been a less-considered factor in proximity literature so far. To our knowledge, Plotnikova and Rake (2014) and Fernandez et al. (2016, 2017) represent the only attempts to analyse all dimensions at once. However, the paper by Plotnikova and Rake (2014) was limited to pharmaceutical research and used only country-level data. The paper by Fernandez et al. (2016) was carried out for all disciplines and factors at the university level, except economic distance, which was measured at the regional level. This paper contributes to the extant empirical literature by providing a joint analysis of proximity notions using data at the university level, with a special focus on organizational and economic proximity, and refining the measure for economic distance to account for differences at the university and province level.

The methodology to address our research is based on data from a set of co-authored articles published between 2001 and 2010 by public universities located in Spain and founded before 1997 to ensure the universities had sufficient time, at least four years, to foster scientific activity and collaboration with other universities[2]. Our data for the econometric model consist of 903 = (43 * 42)/2 pairs of collaborating institutions (observations) from 43 public universities (4 universities were removed because they were founded in 1997 or later), containing 19,736 SCs among Spanish universities in 2006–2010. Our dataset contains information on publications and collaborations in Science and Engineering (excluding social sciences) indexed in the Science Citation Index (SCI) provided by Web of Science (WoS).

The remainder of this paper is organized as follows. "Literature review" section reviews relevant literature on different notions of proximity in two phases. First, we jointly review some relevant literature about geographical, technological, institutional and social proximity as well- studied factors in proximity theories. After that, we focus on organizational and economic factors as the main variables of this paper. "Methodology and data" section provides the methodology and data used. "Descriptive analysis" section presents a brief description of scientific activities across Spanish universities to provide a picture of their scientific output. In "Econometric results" section, we discuss the main results obtained from our econometric model. "Summary and concluding remarks" section presents conclusions and policy implications.

Literature review

The proximity literature has developed a relevant framework to understand different aspects of collaboration, pointing out that different dimensions of proximity may facilitate collaboration playing an important role, as previous research indicates (Boschma 2005; Knoben and Oerlemans 2006; Balland et al. 2015). Until the 1990s, different perspectives in economic geography focused mainly on the notion of spatial proximity, understood as physical distance between economic actors that allows collaboration and learning. Some

[2] Descriptive data include information obtained for previous empirical studies corresponding to a total of 43 Spanish university institutions and their corresponding collaborations with the rest of EU-15 institutions except for France and Denmark (not available data in the EUMIDA dataset).

years later, the French School of Proximity Dynamics set other alternative notions of proximity interacting with spatial or geographical distance (Rallet and Torre 1999; Torre and Gilly 2000; Carrincazeaux et al. 2008). In line with this argument, Boschma (2005) considered a relevant discussion on five dimensions of proximity, geographical, technological, institutional, social and organizational, which have in fact been proposed as analytical tools to understand the underlying process of territorial dynamics (Balland et al. 2015). According to this approach, Marrocu et al. (2013) investigated to what extent the regional inventive activity depends on intra-regional characteristics and the ability to absorb knowledge spillovers channelled and diffused by different types of proximity proposed. Their empirical results show that all proximities have a significant complementary role in generating an important flow of knowledge. Some other papers use collaboration among other research topics and propose to take into account the concept of proximity, distinguishing physical proximity from other forms of proximity as determinants of scientific interaction (Frenken et al. 2009; Hoekman et al. 2010; Hennemann et al. 2012). Some authors have added the notion of economic proximity as a relevant factor to explain the mechanisms of scientific collaboration (Schott 1998; Schubert and Sooryamoorthy 2010; Acosta et al. 2011; Fernández et al. 2016, 2017).

The following paragraphs jointly review some previous literature about geographical, technological, institutional and social proximity. After that, we focus on the relevant literature about the effect of organizational and economic proximity on SC, as investigating this effect is the main goal of this paper.

Geographical, technological, institutional and social proximity

Geographical proximity refers to spatial or physical distance between economic actors. As a large body of literature claims, actors that are spatially concentrated benefit from knowledge externalities. Geographical distance between collaborators has consistently been claimed to decrease the likelihood of collaboration (Jaffe 1989; Katz 1994; Anselin et al. 1997; Ponds et al. 2007). Some other authors have claimed that geographic proximity plays a positive role in collaboration and innovation (Olson and Olson 2000; Howells 2002; Hoekman et al. 2010) since it enhances face-to-face interaction, reflecting the fact that geographical proximity facilitates the establishment of other forms of proximity (Balland et al. 2015). However, the role of geographical proximity and its influence on scientific collaboration and knowledge diffusion remain unclear (Singh 2005; Giuliani and Bell 2005; Giuliani and Arza 2009). Following Boschma (2005), geographical proximity is neither necessary nor sufficient for learning to take place. It is not necessary because other forms of proximity may function as substitutes to solve problems of coordination. It is not sufficient because learning processes can obtain benefits from other proximity dimensions in addition to geographical proximity. In that sense, Boschma (2005) considers geographical proximity playing a complementary role in building and strengthening other types of proximity, which may become even more important.

Cognitive proximity in terms of a shared knowledge base is needed in order to communicate, understand, absorb and process new information successfully (absorptive capacity) (Cohen and Levinthal 1990; Boschma 2005). For example, Scherngell and Barber (2009) and Marrocu et al. (2013) show that technological closeness plays a very relevant role, having a significant complementary role in generating an important flow of knowledge. Since too much distance can hinder efficient knowledge absorption, higher levels of cognitive proximity will encourage new interactions, although there will be less scope for future

learning since the knowledge bases of actors will become more similar (Noteeboom 1999; Balland et al. 2015). Nevertheless, some studies have shown a certain degree of cognitive distance as a potential source of complementarities in order to improve the knowledge base (Nooteboom et al. 2007; Gilsing et al. 2008; Broekel and Boschma 2012). The challenge is to collaborate with actors that provide access to heterogeneous sources of knowledge in order to generate sufficiently diverse complementarities while ensuring the absorption capacity of shared knowledge.

Institutional proximity is, on a macro-level, an enabling factor providing stable conditions for interactive learning, including formal institutions (such as laws and rules to reduce uncertainty and risks) and informal institutions (such as culture, norms and habits to facilitate trust and interactions). A certain degree of similarity in formal and informal institutions contributes to intensifying collaborations by facilitating trust and reducing uncertainty and risks (Boschma 2005; Boschma and Frenken 2009). Several papers have pointed to institutional proximity as a crucial factor promoting collaborations (Gertler 1995; Hoekman et al. 2009, 2010; Etzkowitz and Leydesdorff 2000; Etzkowitz 2003; Ponds et al. 2007).

Social proximity is defined in terms of socially embedded relations between agents at the micro-level. It occurs when relations involve trust based on friendship, kinship and past experience. Social proximity is expected to stimulate interactive learning due to personal relations, trust and commitment (Boschma 2005; Uzzi 1996; Rowley et al. 2000; Fleming et al. 2007). As proximity increases due to past interactions, the cost of future collaborations is likely to decrease because coordination and communication costs are a function of proximity (Balland et al. 2015). Empirically, it is commonly accepted to measure social proximity using collaborations or previous research experiences (Breschi and Lissoni 2009; Frenken et al. 2009; Petruzzelli 2011; Hong and Su 2013; D'Este and Patel 2007; D'Este et al. 2013; Paier and Scherngell 2011).

Organizational proximity

Organizational proximity is defined, according to Boschma (2005), as the extent to which relations are shared in an organizational arrangement (micro-level), either within or between organizations, involving the rate of autonomy and degree of control that can be exerted on organizational arrangements. Low organizational proximity means no ties or weak ties between independent actors. Several papers assume this dimension of proximity as a variable measuring organizations that share the same or similar regulation and routines at a micro-level (Gay and Dousset 2005; Balland 2012; Broekel and Boschma 2012). In this sense, a certain degree of organizational proximity is desirable to reduce uncertainty and opportunism in knowledge creation within and between organizations.

Considering academic collaborations, difficulties arise in assessing organizational proximity in Boschma´s sense due to the absence of hierarchical relations between universities. Cummings and Kiesler (2007) admit that participating universities often have dissimilar institutional structures and different culture and norms, suggesting coordination costs as a significant barrier in multi-university collaborations. In this sense, given the diversity in structure, size and strategy of research organizations, universities cannot be considered homogeneous entities (Mowery and Sampat 2004).

Several papers have analysed patents or publications to determine the different characteristics of universities that affect their research results. Acosta et al. (2012) considered a multilevel framework to identify the effects of university factors on the quality of university

patenting. They review previous literature to stress the importance of particular characteristics of universities affecting the productivity of university scientists. In this literature, special attention is paid to the university size using different indicators such as the number of publications (Giuliani and Arza 2009), department size (Schartinger et al. 2002), number of faculties in each university (Friedman and Silberman 2003), and amount of funding that the university received (Baldini 2006; Landry et al. 2007). Azagra-Caro et al. (2005) also investigated university structure influencing the generation of patents through the composition of universities according to their age, technical orientation or regime of ownership. Hewitt-Dundas (2012) examined whether differences between universities are reflected in their knowledge transfer activity to explain the potential effect that these differences have on knowledge transfer activity. Varga and Horváth (2014) provide an exploratory and econometric analysis on some factors using organizational characteristics such as university size, research intensity, external funding, international embeddedness and university quality. Using a different point of view, Boardman and Corley (2008) measure scientific collaboration using data from a national survey of university scientists to explain the effect of organizational attributes on the behaviour of individual scientists.

In this paper, we adopt a broad view of the concept of organizational proximity, understanding this as the degree of similarity between organizations and assuming that university institutions sharing certain characteristics will behave in a similar way. Therefore, they will adopt attitudes that favour collaboration between them more likely than those very different from each other in terms of characteristics and objectives.

Economic proximity

Economic proximity implies considering differences in the level of economic development as a factor affecting collaboration patterns in general and scientific collaboration between academic institutions in particular.

According to the centre-periphery hypothesis, a greater propensity to collaborate between institutions located in countries or regions with different levels of economic development might be explained by the possibility of gaining access to resources and complementarities (Gaillard 1992; Salager-Meyer 2008). Schubert and Sooryamoorthy (2010) also introduce the concept of marginality, related to the lack of opportunities, reputation, contacts or resources, suggesting that, in general, the periphery would suffer from a stigma that makes it difficult to collaborate with the centre. Some studies provide evidence to back this hypothesis (Schott 1998).

According to Hwang (2008), scientists and engineers have collaborated to obtain advanced knowledge and technology in exchange for financing the production of knowledge. Sonnenwald (2007) considered several cases of international collaboration among scientists allowing access to local communities in exchange for material, training and resources. At a regional level, Acosta et al. (2011) obtained evidence using scientific collaboration to analyse the effect of economic proximity. Their results show that differences in per capita income do not affect collaboration, while having similar levels of resources devoted to R&D play a positive role in favouring collaborations. Fernandez et al. (2016) obtained evidence in line with these results. Using R&D expenditures to assess economic distance, they show that scientific collaboration is stronger among universities located in regions with similar levels of resources devoted to R&D. However, the results for regions located in peripheral countries in Southern Europe show that economic distance promotes academic scientific collaboration (Fernandez et al. 2017). Analysing SC at the international

level, Plotnikova and Rake (2014) found that differences in countries' overall R&D expenditures as percentages of the GDP were negatively related to international SC in pharmaceuticals. Jiang et al. (2018) found similar results for the field of marketing, using data on GDP per capita as a proxy of economic distance. Papers reaching different conclusions recommend interpreting the results with caution. Therefore, additional research is necessary to check whether collaboration is effectively more intense between areas with different levels of economic development and resources.

Methodology and data

Methodology

The methodology to address our research objectives rests on three types of analysis.

First, we employ a descriptive analysis of scientific activities that enables us to provide a picture of the temporal evolution of publications and co-publications across Spanish universities in the period 2001–2010. Therefore, we identify those universities that are more prone to scientific collaboration, allowing us to rank Spanish universities in terms of academic activities (top 10 collaborations).

Second, we analyse how different dimensions of proximity evolved over time, providing a joint analysis of trends in SC and considering two periods of time, 2001–2005 and 2006–2010. In addition, some studies have contributed to the development of proximity theory adopting a dynamic approach to analyse how the influence of proximity changes over time. At this point, it is argued that time plays an important role in the co-evolution of knowledge and proximity, generating a shift in the privilege causal arrow trying to explain how collaboration is based on proximity to a new perspective that considers collaboration encouraging proximity. In this new perspective, the question is whether actors choose others based on proximity characteristics or if their proximity grows because they exchange knowledge. In doing so, collaborating actors also tend to become more similar over time (Padgett and Powell 2012; Balland et al. 2015).

Third, we estimate the influence of different proximity dimensions on Spanish SC using a gravity model at the level of universities. We consider geographical, cognitive, institutional and social proximity, and pay special attention to organizational and economic proximity as underdeveloped factors in the literature. Thus, we contribute to the empirical evidence, using an econometric analysis corresponding to the period 2006–2010, to validate the relevance of these two core notions of proximity, organizational and economic factors, at a national scale.

The econometric model is based on the original gravity equation by Newton, where the dependent variable is SC_{ij} between university i and university j as a function of the characteristics of the origin i, the characteristics of the destination j and some degree of proximity between both universities. In doing so, this gravity equation suggests including a measurement of the mass of publications of each university, $\mathbf{Pub}_i$ and $\mathbf{Pub}_j$ (in logarithms), and referring to the preceding period, 2001–2005, to avoid endogeneity (Abramo et al. 2009a, b; Lee and Bozeman 2005). Following the relevant literature reviewed above, we include our explanatory variables in two steps.

First, we propose to estimate the influence of well-established notions of proximity: geographical, cognitive, institutional and social proximity. The variables are as follows:

- **Geo**$_{ij}$ is the geographical distance between universities *i* and *j*.
- **Cogn**$_{ij}$ tests cognitive or technological proximity; it was built as a correlation coefficient calculated by Paci and Usai (2009) for the composition of scientific papers from 12 disciplines for the period 2001–2005 between university *i* and university *j*[3], with 0 as the minimum distance, i.e., identical specialization, and 1 as the maximum distance, i.e., completely different specialization[4].
- **Inst**$_{ij}$ is a dummy variable capturing institutional proximity; it has a value of 1 when universities *i* and *j* are located in the same NUTS-2 region, and 0 when they are located in different NUTS-2 regions.[5]
- **Soc**$_{ij}$ is a measure of social proximity; it has a value of 1 if universities *i* and *j* have collaborated for the preceding 5-year period, 2001–2005. It has a value of 0 otherwise.

In the second step, we test the effect of two more notions of proximity, organizational and economic proximity, as underdeveloped factors in the literature about university knowledge diffusion.

- Organizational proximity: Assuming difficulties in assessing organizational proximity in Boschma's sense since it tries to capture a complex phenomenon, we suggest that university institutions sharing certain characteristics will behave in a similar way. We propose three variables to capture similarities in order to explain the effects of organizational attributes on academic collaborations as factors proxying organizational characteristics. **Staff**$_{ij}$ is the absolute difference in total staff (teaching and researching staff) calculated as the average for the period 2006–2010 (in logarithms). **Year**$_{ij}$ is the absolute difference in years since universities *i* and *j* were founded, meaning the difference in age of the collaborating universities. **Int**$_{ij}$ is the international vocation of universities *i* and *j* calculated as a ratio between international collaborations and total collaborations in the period 2006–2010.
- Economic proximity: We propose two economic variables to assess economic proximity. **Regional_GDP**$_{ij}$ considers differences in economic development of the NUTS-3 region (provinces) where universities *i* and *j* are located, calculated as the absolute difference (in logarithms) in the average per capita GDP. This variable has been taken into account considering a five-year lag because it is expected that economic resources take time to be reflected in scientific output (Regional_GDP$_{ij}$ was alternatively calculated considering a two-year lag and yielded similar estimation results). **Fund**$_{ij}$, as a proxy, captures absolute differences (in logarithms) in financial funding obtained from the Spanish Research and Development Program in the available year 2008[6]. This variable

[3] Publications have been classified into 12 scientific disciplines following Tijssen and van Leeuwen (2003) and Torres-Salinas et al. (2011), again using the full counting method for those publications included in journals related to more than one discipline.

The 12 scientific disciplines are as follows: Agricultural and Food sciences; Chemistry and Chemical Engineering; Earth and Environmental Sciences; Engineering, Information and Communication Technologies, Life Sciences and Biology, Materials Science Mathematics, Medicine, Biomedicine and Health Sciences, Multidisciplinary Sciences, Pharmacology and Physics and Astronomy.

[4] We provide the adjacency matrix on cognitive distance as electronic supplementary material to this article.

[5] In the Spanish case these territorial units represent administrative and policy authorities (Tojeiro-Rivero and Moreno 2019).

[6] Note that yearly data on university funding was not available to the authors. We could only access Fund-

has been weighted by taking into account the average total staff for the period 2006–2010.

The analysis of count data following the full-counting process implies crediting 1 publication to each co-author institution. Since estimates obtained from linear regression can be inconsistent, inefficient and biased (Amano and Fujita 1970; Long 1997; Cameron and Trivedi 2009, 2013), we put forward a count model (Poisson or negative binomial). As in most previous studies, our baseline specification initially assumed that the dependent variable followed a Poisson distribution. However, one limitation of the Poisson model is that it assumes the mean and variance of the dependent variable are equal, so this framework breaks down when the data are overdispersed. In this case, the standard errors of the Poisson model are biased towards the low end, giving spurious high values for the t statistics (Cameron and Trivedi 1986). Therefore, we consider a negative binomial (NB) model that permits overdispersion[7]. The NB model assumes that the variance is a quadratic function of the mean. The approaches of the density function, logarithmic likelihood function, first order conditions, etc. are discussed in detail in Cameron and Trivedi (1998).

Data

The paper uses data from a set of co-authored articles published between 2001 and 2010 by public universities located in Spain. Our dataset contains information on publications and collaborations in Science and Engineering (excluding social sciences) indexed in the Science Citation Index (SCI) provided by Web of Science (WoS).

Following a similar procedure to Fernández et al. (2016), our sample consists of 903 = (43 * 42)/2 pairs of collaborating institutions (observations) from 43 public universities[8] containing 19,736 SCs among Spanish universities in 2006–2010. Co-authored articles have been assigned to universities following the full-counting process (i.e. crediting 1 publication to each co-author institution). In other words, we have counted the number of inter-university co-publications for each institution. Afterwards, SCs have been placed into a symmetrical matrix containing all co-publications between university *i* and university *j*. Subsequently, we link each university to information at the institutional level contained in the EUMIDA dataset (Data Collection 1), which contains organizational information such as foundation year. Data about staff were obtained from the official statistics of the Spanish government. Economic data stemmed from two sources. Information on GDP of the province in which the university is located stemmed from the National Institute of Statistics (INE). We retrieved data about financial funding obtained by each university from the Spanish Research and Development Program in the available year 2008.

Footnote 6 (continued)
ing information related to year 2008. Therefore, distance in funding is calculated based on information from 2008.

[7] LR test alpha confirmed better results for NB than the Poisson model.

[8] Note that Spain accounts for 47 public universities. To ensure the universities had enough time to foster scientific activity and collaborations with other universities, four universities were removed because they were founded after 1997.

Table 1 Publications and collaborations of Spanish universities. *Source*: WoS. Own elaboration

	2001	2004	2007	2010	01–05	06–10	Increase 01–10
A. Pub.	16,426	19,027	24,667	30,241	90,887	131,960	0.841
B. Col.	5333	6504	9235	12,191	31,010	50,989	1.286
C. Staff	NA	NA	88,796	94,875	85,875	91,318.2	NA
A/C	NA	NA	0.28	0.32	1.06	1.45	–
B/C	NA	NA	0.10	0.13	0.36	0.56	–
B/A	0.32	0.34	0.37	0.40	0.34	0.39	–

Descriptive analysis

Evolution of scientific output

As a first approximation and for context, scientific activities across Spanish universities are listed to provide a picture of the scientific output[9]. Table 1 reports the evolution of the total number of publications and collaborations during 2001–2010. Following the information from the original sample, there was an important increase in total publications (84.1%) and collaborations (128.6%) during the period of analysis. Differences in rates show greater growth in collaboration, which coincides with the current tendency of universities to devote resources to co-authored papers. This tendency is also observed if publications and collaborations are weighted by staff. Finally, Table 1 shows an important increase in terms of the intensity of scientific collaboration as a percentage of total publications during 2001–2010.Next, we provide Tables 2, 3, 4 and 5 with the only purpose of illustrating those Spanish universities with the highest collaboration rates. Table 2 ranks the top 10 Spanish universities in terms of scientific collaboration.[10] The data show that the top 10 collaborative universities accounted for 50.82% of the total number of co-authored papers in 2001–2005 but decreased to 50.55% during 2006–2010. This evidence indicates a high concentration in terms of collaboration among a limited number of universities, with a slight and positive trend to decrease the concentration in terms of collaboration among Spanish universities. Tables 3 and 4 normalize collaborations according to the size of the staff and total publications, showing notable changes in the rank in both cases. Doing so, some less relevant universities appear in the top 10 collaborations list. Differences in the two considered periods of time, 2001–2005 and 2006–2010, confirm a higher propensity to collaborate among Spanish universities over the time, as we expected.

Table 5 shows the top 10 pairs of Spanish collaborating universities. It is worth mentioning that all pairs in the top 10 list include universities located in the same region. These results allow us to obtain a first glance about the importance of proximity to encourage collaborations. Additionally, the top 10 pairs of collaborations account for 21.34% of the total number of co-authored papers in 2001–2005. The percentage decreases to 17.42% in the period 2006–2010, once again confirming a lower concentration in terms of collaboration among Spanish university over the time.

[9] As mentioned above, we display data from 43 out of 47 public Spanish universities.

[10] We indicate in parentheses the autonomous community or region where the university is located.

Table 2 Top 10 collaborations. *Source*: WoS. Own elaboration

	No.	%
2001–2005		
1. University of Barcelona (Catalonia)	2606	0.084
2. Complutense University of Madrid (Madrid)	2188	0.071
3. University of Valencia (Valencian Community)	1842	0.059
4. Autonomous University of Barcelona (Catalonia)	1718	0.055
5. Autonomous University of Madrid (Madrid)	1574	0.051
6. University of Granada (Andalusia)	1356	0.044
7. University of Santiago Comp. (Galicia)	1323	0.043
8. University of Zaragoza (Aragon)	1078	0.035
9. University of Seville (Andalusia)	1066	0.034
10. Polytechnic University of Catalonia (Catalonia)	1011	0.033
Top 10	15,762	50.82
Others	15,248	49.17
Total	31,010	100
2006–2010		
1. University of Barcelona (Catalonia)	4518	0.089
2. Autonomous University of Barcelona (Catalonia)	3189	0.063
3. Complutense University of Madrid (Madrid)	3129	0.061
4. University of Valencia (Valencian Community)	2949	0.058
5. Autonomous University of Madrid (Madrid)	2412	0.047
6. University of Granada (Andalusia)	2290	0.045
7. University of Santiago Comp. (Galicia)	1986	0.039
8. Polytechnic University of Catalonia (Catalonia)	1850	0.036
9. University of Zaragoza (Aragon)	1817	0.036
10. University of Seville (Andalusia)	1635	0.032
Top 10	25,775	50.55
Others	25,214	49.45
Total	50,989	100

Table 6 provides some details on collaborating pairs, showing an increase from 745 to 833 pairs, growing the number of total collaborations from 11,904 to 19,736 (65.79%). Focusing on possible pairs of universities, 82.50% had co-authored papers in 2001–2005, increasing to 92.25% in 2006–2010. Similarly, the number of average collaborations among pairs (collaboration intensity) has increased from 15.98 to 23.69, confirming a higher propensity for collaborations.

Evolution of collaboration across proximity notions

It is worth mentioning that certain studies have introduced some advances in proximity theories adopting a dynamic approach to analyse how the influence of proximity changes over time (Padgett and Powell 2012; Balland et al. 2015). As mentioned before, it is argued that time plays an important role in the co-evolution of knowledge and proximity.

To show how Spanish academic SC evolved over time and across distance, Table 7 displays the mean and standard deviation of each proximity dimension in 2001–2005 and 2006–2010. The geographical distance among collaborating pairs shows an increase over time (1.89%).

Table 3 Top 10 collaborations/staff. *Source*: WoS. Own elaboration

2001–2005	
1. Autonomous University of Madrid (Madrid)	0.663
2. University of Jaen (Andalusia)	0.614
3. University of Santiago Comp. (Galicia)	0.603
4. Autonomous University of Barcelona (Catalonia)	0.592
5. University of Barcelona (Catalonia)	0.591
6. University of Valencia (Valencian Community)	0.532
7. University of Vigo (Galicia)	0.520
8. University of Cantabria (Cantabria)	0.438
9. Pompeu Fabra University (Catalonia)	0.429
10. University of Almeria (Andalusia)	0.404
Total	0.361
2006–2010	
1. Autonomous University of Madrid (Madrid)	0.991
2. University of Barcelona (Catalonia)	0.957
3. Autonomous University of Barcelona (Catalonia)	0.939
4. University of Santiago Comp. (Galicia)	0.896
5. University of Jaen (Andalusia)	0.819
6. University of Valencia (Valencian Community)	0.807
7. Pompeu Fabra University (Catalonia)	0.790
8. University of Vigo (Galicia)	0.744
9. Polytechnic University of Catalonia (Catalonia)	0.698
10. University of Granada (Andalusia)	0.623
Total	0.558

The cognitive or technological dimension evidences a slight increase (0.28%), thus showing a different specialization (higher distance) among collaborating pairs between university *i* and university *j* over time. Institutional proximity decays over time (by 9.39%), suggesting a stronger trend towards interregional collaborations. We cannot show evidence on trends in social proximity over the period of analysis since we do not have data on previous collaborations for the period 2001–2005.

Focusing on organizational proximity, variables capturing differences in size decay over time (2.99%). Second, variables capturing differences in the foundation years of universities also show a decreasing trend (by 4.35%). Third, the international vocation average decrease over time between Spanish collaborating universities in the period 2006–2010 (1.19%).

Finally, two variables measure economic proximity. The mean values for differences in GDP also decay over time (1.16%). It is not possible to show trends for those pairs collaborating during 2001–2005 and, then, for those pairs collaborating during 2006–2010 on financial funding obtained from the Spanish Research and Development Program since the only available year is 2008.

Table 4 Top 10 collaborations/publications. *Source*: WoS. Own elaboration

2001–2005	
1. University of Burgos (Castilla-Leon)	0.593
2. University of Huelva (Andalusia)	0.589
3. University of Jaen (Andalusia)	0.565
4. Pompeu Fabra University (Catalonia)	0.518
5. University of La Rioja (La Rioja)	0.472
6. University of Girona (Catalonia)	0.452
7. Jaume I University (Valencian Community)	0.427
8. University of Almeria (Andalusia)	0.409
9. University of Vigo (Galicia)	0.403
10. University of Castilla-La Mancha (Castilla-La Mancha)	0.402
Total	0.341
2006–2010	
1. University of Jaen (Andalusia)	0.578
2. University of Huelva (Andalusia)	0.543
3. Pompeu Fabra University (Catalonia)	0.530
4. University of Burgos (Castilla-Leon)	0.527
5. Jaume I University (Valencia)	0.469
6. University of Almería (Andalusia)	0.429
7. University of Girona (Catalonia)	0.423
8. University of Valencia (Valencian Community)	0.422
9. University of Granada (Andalusia)	0.411
10. University of Castilla-La Mancha (Castilla-La Mancha)	0.411
Total	0.386

Econometric results

To estimate the influence of different proximity dimensions affecting Spanish academic collaborations, we establish an econometric framework using cross-sectional data, as mentioned above. Our dependent variable is the count of SC_{ij} between university i and university j. Table 8 shows the descriptive statistics of the variables included in our models.

Table 9 shows the results of our three estimations using negative binomial models. Model 1 displays the results of our base model jointly considering geographical, technological, institutional and social proximity as well-established factors in proximity theories. Variables capturing the mass of publications of each university show positive and significant coefficients, meaning an increase in the number of collaborations between university i and university j as the number of publications of each university rises. Spanish SC decreases with geographical distance, as the negative and significant coefficient shows. The variable capturing cognitive or technological proximity shows a negative and significant coefficient, meaning that identical scientific specialization (minimum distance) matters to encourage collaborations between Spanish universities. Institutional proximity has a positive and significant coefficient, indicating that universities located in the same region are more prone to collaborate. This result additionally confirms that physical proximity matters to foster SC. Our last variable in this base model, social proximity, has a positive and significant coefficient, revealing that Spanish universities collaborate more likely when they have previously collaborated.

Table 5 Top 10 collaborating pairs. *Source*: WoS. Own elaboration

University *i*	University *j*	No.	%
2001–2005			
1. Barcelona (Catalonia)	Autonomous Barcelona (Catalonia)	399	0.034
2. Polytechnic Valencia (Valencian Community)	Valencia (Valencian Community)	341	0.029
3. Vigo (Galicia)	Santiago Comp. (Galicia)	340	0.029
4. Jaen (Andalusia)	Granada (Andalusia)	283	0.024
5. Complutense Madrid (Madrid)	Autonomous Madrid (Madrid)	267	0.022
6. Polytechnic Catalonia (Catalonia)	Barcelona (Catalonia)	254	0.021
7. Jaume I (Valencian Community)	Valencia (Valencian Community)	174	0.015
8. Santiago Comp. (Galicia)	A Coruña (Galicia)	168	0.014
9. Polytechnic Madrid (Madrid)	Complutense Madrid (Madrid)	166	0.014
10. Granada (Andalusia)	Almeria (Andalusia)	148	0.012
Top 10		2540	21.34
Others		9364	78.66
Total		11,904	100
2006–2010			
1. Barcelona (Catalonia)	Autonomous Barcelona (Catalonia)	679	0.034
2. Polytechnic Valencia (Valencian Community)	Valencia (Valencian Community)	498	0.025
3. Vigo (Galicia)	Santiago Comp. (Galicia)	375	0.019
4. Jaen (Andalusia)	Granada (Andalusia)	359	0.018
5. Complutense Madrid (Madrid)	Autonomous Madrid (Madrid)	330	0.017
6. Polytechnic Catalonia (Catalonia)	Barcelona (Catalonia)	311	0.016
7. Polytechnic Madrid (Madrid)	Complutense Madrid (Madrid)	282	0.014
8. Santiago Comp. (Galicia)	A Coruña (Galicia)	210	0.011
9. Jaume I (Valencian Community)	Valencia (Valencian Community)	207	0.010
10. Polytechnic Catalonia (Catalonia)	Autonomous Barcelona (Catalonia)	187	0.009
Top 10		3438	17.42
Others		16,298	82.58
Total		19,736	100

Table 6 Collaborations and collaboration intensity 2001–2010. *Source*: WoS. Own elaboration

	01–05	06–10
A. Pairs	903	903
B. Collaborating pairs	745	833
C. Total collaborations	11,904	19,736
B/A	82.50	92.25
Collaboration intensity (C/B)	15.98	23.69

To summarize, all results show the significant coefficients expected from the literature review. Table 9 includes models 2 and 3 to test two core notions of proximity, organizational and economic proximity, as underdeveloped factors in the previous literature about university knowledge diffusion.Model 2 focuses on organizational proximity. We add three variables to test size, foundation year and international vocation to capture

Table 7 Proximity dimensions (mean and standard deviation)

	01–05	06–10	Increase (%)
Geographical distance			
Geo_{ij}	5.7771 (4.46)	5.8867 (4.49)	1.89
Cognitive proximity			
$Cogn_{ij}$	0.7830 (0.04)	0.7852 (0.04)	0.28
Institutional proximity			
$Inst_{ij}$	0.0980 (0.30)	0.0888 (0.28)	− 9.39
Social proximity			
Soc_{ij}	–	0.8691 (0.34)	–
Organizational proximity			
$Staff_{ij}$	1450.05 (1178.30)	1406.71 (1158.37)	− 2.99
$Year_{ij}$	231.30 (247.01)	221.24 (246.13)	− 4.35
Int_{ij}	0.3876 (0.07)	0.3830 (0.07)	− 1.19
Economic proximity			
$Regional\_GDP_{ij}$	5615.51 (4731.64)	5550.10 (4625.55)	− 1.16
$Fund_{ij}$	–	1323.04 (1139.12)	–
N. Obs.	745	833	11.81

Table 8 Descriptive statistics

	Mean	Standard deviation	Min	Max
SC_{ij}	21.856	45.273	0	679
Pub_i	1981.68	1679.04	358	8563
Pub_j	2245.61	1832.30	358	8563
Geo_{ij}	6.025	4.543	0.009	23.413
$Cogn_{ij}$	0.786	0.037	0.681	0.961
$Inst_{ij}$	0.083	0.276	0	1
Soc_{ij}	0.825	0.380	0	1
$Staff_{ij}$	1356.20	1137.61	0.799	5809.6
$Year_{ij}$	210.09	245.273	0.1	779
Int_{ij}	0.380	0.068	0.217	0.567
$Regional\_GDP_{ij}$	5435.25	4536.03	0	25,471.76
$Fund_{ij}$	1300.23	1122.87	1.443	5360.45
N. Obs. 903				

characteristics of the Spanish universities to explain the effects of organizational attributes on academic collaborations. Differences in size between Spanish universities are not relevant to explaining academic collaborations. Differences in foundation year show

Table 9 Estimation results from NB regressions

	Model 1		Model 2		Model 3	
	Coefficient (SE)	Sig.	Coefficient (SE)	Sig.	Coefficient (SE)	Sig.
Cons	− 7.267 (0.822)	***	− 7.460 (0.824)	***	− 7.665 (0.822)	***
Mass						
Pub_i	0.642 (0.038)	***	0.664 (0.043)	***	0.669 (0.042)	***
Pub_j	0.793 (0.037)	***	0.823 (0.041)	***	0.822 (0.041)	***
Geographical distance						
Geo_{ij}	− 0.034 (0.006)	***	− 0.030 (0.006)	***	− 0.032 (0.006)	***
Cognitive proximity						
$Cogn_{ij}$	− 1.999 (0.774)	**	− 1.864 (0.772)	**	− 2.116 (0.772)	***
Institutional proximity						
$Inst_{ij}$	1.519 (0.092)	***	1.536 (0.092)	***	1.552 (0.092)	***
Social proximity						
Soc_{ij}	0.918 (0.088)	***	0.914 (0.088)	***	0.897 (0.088)	***
Organizational proximity						
$Staff_{ij}$			0.019 (0.025)		0.016 (0.024)	
$Year_{ij}$			0.032 (0.013)	**	0.038 (0.013)	***
Int_{ij}			− 1.516 (0.509)	***	− 1.817 (0.515)	***
Economic proximity						
$Regional\_GDP_{ij}$					0.002 (0.014)	
$Fund_{ij}$					0.074 (0.022)	***
LR test alpha (1)	5594.16	***	5433.31	***	5367.16	***
Log likelihood	− 3080.35		− 3073.49		− 3067.84	
LR stat	1091.54	***	1105.65	***	1116.96	***
Pseudo-R2	0.1505		0.1524		0.1540	
N. Obs.	903		903		903	

(1) Overdispersion test. Cameron and Trivedi (1990)

*$p<0.10$ **$p<0.05$ ***$p<0.001$

Table 10 Estimation results from NB regressions (convergence regions or not)

	Model 3A		Model 3B		Model 3C	
	Non-convergence regions		Convergence–non convergence regions		Convergence regions	
	Coefficient (SE)	Sig.	Coefficient (SE)	Sig.	Coefficient (SE)	Sig.
Cons	− 6.303 (1.084)	***	− 10.799 (1.487)	***	− 3.002 (4.948)	***
Mass						
Pub_i	0.600 (0.056)	***	0.808 (0.069)	***	0.623 (0.161)	***
Pub_j	0.794 (0.053)	***	0.894 (0.071)	***	0.758 (0.172)	***
Geographical distance						
Geo_{ij}	− 0.024 (0.007)	***	− 0.034 (0.013)	***	− 0.306 (0.047)	***
Cognitive proximity						
$Cogn_{ij}$	− 3.432 (0.943)	**	1.334 (1.529)		− 7.743 (6.159)	
Institutional proximity						
$Inst_{ij}$	1.556 (0.120)	***	Omitted		0.583 (0.220)	***
Social proximity						
Soc_{ij}	0.967 (0.126)	***	0.867 (0.127)	***	1.094 (0.435)	**
Organizational proximity						
$Staff_{ij}$	0.038 (0.034)		− 0.029 (0.040)		− 0.012 (0.069)	
$Year_{ij}$	0.053 (0.017)	***	0.012 (0.022)		0.042 (0.039)	
Int_{ij}	− 1.195 (0.683)	*	− 3.523 (0.869)	***	0.778 (2.221)	
Economic proximity						
$Regional\_GDP_{ij}$	− 0.003 (0.025)		− 0.002 (0.019)		0.063 (0.042)	
$Fund_{ij}$	0.064 (0.032)	**	0.062 (0.032)	*	0.134 (0.072)	*
LR test alpha (1)	2693.94	***	1203.04	***	544.78	***
Log likelihood	− 1520.89		− 1224.13		− 288.76	
LR stat	605.49	***	351.94	***	135.33	***
Pseudo-R2	0.1660		0.1257		0.1898	
N. Obs. (Total = 903)	435		390		78	

(1) Overdispersion test. Cameron and Trivedi (1990)

*$p < 0.10$ **$p < 0.05$ ***$p < 0.001$

a positive and significant coefficient. This result means that different ages of the universities affect collaborations, suggesting that younger universities try to seek expertise in traditional and older universities, which were founded years ago. The negative and significant coefficient of the variable accounting for international vocation may imply a substitutive effect between national and international collaborations. This means a lower rate of national collaborations between collaborating pairs when universities are engaged in a higher international activity.

Model 3 validates the relevance of two economic factors encouraging Spanish collaborations. Differences in GDP do not show relevance to explaining SC among those Spanish universities located in areas with different levels of per capita income. Regarding differences in financial funding obtained, the variable shows a positive and significant coefficient, suggesting a stronger rate of collaboration among universities with different levels of funding. Model 3 has higher overall fit than Model 1 and Model 2 (Log-Likelihood: − 3067.84) and explains the most variance in citation counts (Pseudo R2:0.1540).

Finally, Table 10 displays different estimation results by separating university pairs according to the level of economic development of the region in which they are located. For this purpose, we distinguish between convergence and no convergence regions[11]. Model 3A includes university pairs where both institutions are located in no convergence regions. The results are similar to Model 3. Models 3B and 3C include pairs where either one university or both are located in a convergence region. Both cases show some differences, mainly indicating that geographical, institutional and social proximity are more relevant variables to explain Spanish collaborations between universities when one or both universities are located in a less developed region.

Summary and concluding remarks

The main objective of this paper was to explore the effects that two core notions of proximity, organizational and economic factors, have on scientific collaborations (SCs) among Spanish universities, which are institutions in a peripheral country. Following the proximity perspective as a framework, we use a set of co-authored articles indexed in the Science Citation Index (SCI) provided by Web of Science (WoS) and published between 2001 and 2010 by 903 pairs of collaborating universities.

From our descriptive analysis, we can conclude that there has been an important increase in total publications (84.1%) and collaborations (128.6%) during the period of analysis, with differences in rates showing greater growth in collaborations, which coincides with the current tendency of universities to conduct research towards co-authored papers. This tendency is also observed in relative terms by size. Ranking the top 10 Spanish universities in terms of scientific collaborations, the results show a high concentration of collaboration among a few universities, with a slight and positive trend to decrease the concentration in terms of collaboration among Spanish universities, accounting for 50.82% of the total number of co-authored papers in 2001–2005 and decreasing to 50.55% during

[11] Convergence regions are those included in the "2006/595/EC: Commission Decision of 4 August 2006 drawing up the list of regions eligible for funding from the Structural Funds under the Convergence objective for the period 2007–2013" (published in the Official Journal of the European Union and notified under document number C(2006) 3475). Table 11 included in the "Appendix" of this manuscript identifies Spanish universities in our sample located at convergence regions.

2006–2010. Normalizing collaborations according to the size of the staff and total publications, descriptive data show notable changes in the rank in both cases. Doing so, some less relevant universities appear in the top 10 collaborations list, showing differences in the two considered periods of time, 2001–2005 and 2006–2010, confirming a higher propensity to collaborate among Spanish universities over time. It is worth mentioning that all top 10 pairs of Spanish universities in terms of collaborations comprise universities located in the same region. Thus, these findings again support the importance of proximity to encourage collaborations.

Our results also show how Spanish academic SC evolves over time and across distance, revealing an increase in the geographical and cognitive distance among collaborating pairs over time and showing a different specialization (higher distance) among collaborating pairs over time. Institutional proximity decays over time, suggesting a stronger trend towards interregional collaborations. Focusing on organizational proximity (differences in size, differences in foundation year and international vocation), the average decays over time between Spanish collaborating universities. From variables measuring economic proximity, we conclude that the mean values for differences in GDP show a slight decrease over time. It has not been possible to show trends in the evolution of financial funding obtained from the Spanish Research and Development Program and trends in social proximity since data were not available to us for the preceding period.

For the main purpose of this paper, all results from our econometric model jointly considering geographical, cognitive, institutional and social proximity as widely studied factors in proximity theories show significant coefficients aligned with the previous literature. Regarding organizational proximity, we conclude that differences in size between Spanish universities are not relevant to explaining academic collaborations, while differences in age among universities positively affect SC. This result could indicate that younger universities try to seek expertise from traditional and older universities, while the latter gain access to a wider and renewed ground of ideas. The negative sign of the coefficient for international vocation may suggest a substitutive effect between national and international collaborations, bringing a lower rate of national collaborations between collaborating pairs when universities are engaged in a higher international activity. Finally, our model has considered two economic factors encouraging Spanish SC. On the one hand, differences in GDP are not relevant to explaining SC among those Spanish universities located in provinces with different levels of per capita income. This result may be explained because this research has been conducted among Spanish universities located in regions where differences in economic level are not as relevant in terms of the centre-periphery hypothesis. On the other hand, the results for the differences in financial funding show a stronger rate of collaboration among universities with different levels of funding. In other words, universities with less access to financial funding try to collaborate with other universities with more resources, and vice versa. This may suggest that universities look for complementarities through collaborations with partners that have dissimilar access to financial funding.

Our results allow us to draw some policy implications. First, the effect of different notions of proximity should be considered. Traditional incentives have been oriented towards promoting SC across geographical distance (see, for instance, European Framework programmes), but we have shown that other notions of proximity also have a weight in SC (e.g. organizational and economic proximity). Therefore, we propose that incentives to collaboration would be more effective if they adopted a multi-dimensional approach, i.e. considers the role of cognitive, institutional, social, organizational and/or economic proximity as factors shaping SC, in addition to the well-known effect of geographical proximity. Second, we have shown that the effect of different notions of proximity differs according to

the level of development of the region in which the universities are located. For example, there is a trade-off between international and national SC for those pairs of universities in which one belongs to a convergence region and the other does not. This substitution effect is not found in SC where both universities are located in the same region type (convergence or not convergence).

Based on the limitations of this study, we suggest avenues for further research. First, further investigation could test whether proximity notions act as complements or substitutes for one another and whether the regional context plays a role in that relationship. Second, future contributions could test if our results are consistent when considering data from Scopus or from Social Science Citation Index. Third, it is known that rankings are used by government and universities to inform and guide policy design and decision making (Hazelkorn 2014) and that the choice on the ranking(s) used as a standard affects policy design (Moed 2017). Therefore, upcoming research could address how university rankings affects scientific collaboration.

Appendix

See Table 11.

Table 11 Universities located in convergence regions

University	Region
University of Almería	Andalusia
University of Cádiz	Andalusia
University of Córdoba	Andalusia
University of Granada	Andalusia
University of Huelva	Andalusia
University of Jaén	Andalusia
University of Málaga	Andalusia
University of Seville	Andalusia
University of Castilla-La Mancha	Castilla-La Mancha
University of Extremadura	Extremadura
University of A Coruña	Galicia
University of Santiago Comp.	Galicia
University of Vigo	Galicia

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