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Patterns of collaboration for technology transfer in Spanish universities

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ABSTRACT

Universities are relevant actors in research and development (R&D) and, increasingly, in innovation. These institutions play a significant role in the generation and transfer of scientific and technical knowledge. They may also adopt an orchestration role, in order to combine diverse national and international sources of knowledge through collaboration networks that can enhance their ability to transfer it to industry and society. In this paper, we seek to demonstrate that, if this pattern is confirmed, larger benefits can be achieved and translated into better performance and greater impacts on the development of local innovation ecosystems. Using data on patents granted to universities by the United States Patent and Trademark Office (USPTO) from 1990 to 2017, we study the technological performance of Spanish universities to illustrate how collaboration patterns affect the relative impact on their innovative activities. Our contribution identifies a dual complementary and geographically dispersed pattern of collaboration in the evolution of universities' technological performance, while the existence of public-private partnerships and the generation of international linkages are found to be prevalent factors (even dominant over R&D).

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University patents; collaboration; knowledge generation; technology transfer

1. Introduction

Over recent decades, universities have become increasingly relevant actors within the national systems of science, technology, and innovation. Their central role in functions of education and training contribute to the provision of higher levels of qualification to local labour markets, improving human capital as well as the production and dissemination of scientific and technological knowledge. Combined with the indisputably positive impact of basic science on development, knowledge transfer to the local productive sector may also serve a leveraging function, with positive outcomes in the innovation performance of regional and national economies (Etzkowitz 2008). In fact, in addition to their teaching and research activities, universities play a crucial role in the consolidation of

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a local innovation ecosystem, often establishing strong linkages with other R&D centres, private companies, technology parks, and public institutions, and they are thus considered active agents in the knowledge-based economy (Leydesdorff 2010). The general assumption has been that these connections enable universities to generate new knowledge that serves as a powerful source of innovation, productivity, and economic growth and development (Bercovitz and Feldmann 2006; Alexander et al. 2020). However, these arguments may differ across regions; less known is that universities can play an orchestration role to integrate diverse knowledge sources from distinct agents and different geographical origins, and this may affect knowledge transfer.

The related literature is focused mostly on relationships between universities and local agents, due to the relevance of these linkages as drivers in the generation of innovative clusters (Gunasekara 2006; Uyarra 2010). Attention has also been paid to science-industry linkages and the potential bidirectional knowledge transfer between universities and firms, with certain agreement that an interactive and collaborative process of co-creation of new knowledge can promote innovation ecosystems (Guimón and Paunov 2019). In that context, university networks linkages with firms and other research centres in the same or a nearby location can be important mechanisms that ultimately affect technological performance through the generation of new patentable knowledge (Acosta, Coronado, and Martínez 2018; Fonseca and Nieth 2021). While the effectiveness of these connections is assumed to be conditioned by the geographical proximity of the university and the agents involved in the innovation process (D'este and Iammarino 2010; Ortega 2011), recent findings point to the role of universities in sourcing and disseminating foreign knowledge in local contexts through their involvement in global networks (Petruzzeli and Murgia, 2020).

This paper moves a step forward in the analysis of knowledge transfer activities by universities, providing new arguments on the combination of dimensions that contribute to understanding collaboration patterns that strengthen the impacts of their innovation outcomes at a regional level. Our first research question concerns *the relative relevance of the different sources of knowledge that can be orchestrated by universities through their collaboration linkages with both industrial firms and other research organizations*. The second question concerns how *universities may combine certain key dimensions such as the types of partners and the geographical scope of their linkages, and the extent to which they interact and affect the universities' technological performance and knowledge transfer*.

In order to explore these research questions, we draw distinctions among potential partners according to their nature (private companies, research centres) and their geographical location. We argue that such distinctions may contribute to defining the technological performance profile of universities, also helping to clarify the impact of universities on the development of innovation ecosystems, it being necessary to integrate both national and international collaboration linkages into the analysis of patents (Carlsson 2006; Petruzzeli & Murgia, 2020). We contribute to the existing literature by showing how collaboration between researchers and institutions in both national and international contexts in the patenting activity of universities represent significant leveraging factors that potentially enhance knowledge transfer. Our findings also contribute to identifying relevant aspects that may foster significant implications in terms of strategic decisions for stakeholders, especially in those regions that underperform in terms of innovation.

This analysis is based on Spanish universities. Several legislative reforms in Spain have aimed to reorient university activities to improve their contributions to the generation and dissemination of new knowledge to both the productive sector and society. The rationales for such reform have been to open space for larger contributions, to build intermediate organizations, and to enhance collaboration with the productive sector.[1] These changes to the regulatory framework have led to increases in the share of university-owned patenting, which doubled in recent years from a ratio of 9.9% of total patent applications in 2005–18.2% in 2018 (FECYT 2019). However, the contribution by universities to patenting activity in Spain remains modest in absolute numbers, and this is coherent with the low propensity to patent (shared with industry) in the national innovation system (Molero 2004), Spain being a moderate innovator among EU countries (European Commission 2018). Although we do not investigate the contribution of universities to patenting activity in Spain, the relevance of university collaboration networks in the generation of new knowledge and its potential transfer justify our consideration that this country constitutes an interesting case for study.

Our main data source was the patent database of the United States Patent Office (USPTO), seeking patents that involved at least one Spanish university during the period 1990–2017. Patent data were then used to analyze the geographical distribution of inventors and assignees, both nationally and internationally, as well as the distribution of the types of partners with which Spanish universities collaborate in patents. This allows us to determine the influence and scope of networks in the knowledge generation and transfer of Spanish universities.

In section 2, we present a literature review that supports our specific analyses regarding the links between universities and innovation and the importance of patents as a mechanism for knowledge transfer to the productive and social sectors. In section 3, the USPTO patent database is briefly described, along with the method of data collection and the econometric model specification. In section 4, we present the empirical analysis of the relevant factors that explain patents from universities, taking into account the nature and geography of the collaboration linkages. In section 5, some concluding remarks and the limitations of our analysis are presented.

2. Background

2.1. The role of universities in knowledge transfer

Universities play a strategic role in the generation and dissemination of scientific and technological knowledge within countries, this being crucial to enhancing the emergence of business and the consolidation innovation ecosystems (Carlsson et al. 2002). Among other conceptual frameworks, the triple helix and innovation systems perspectives propose that interactions between academia, industry, and governments are very relevant within a knowledge-based economy (Etzkowitz and Leydesdorff 2000; Gunasekara 2006; Borras and Edquist 2019). The university is now expected to combine responsiveness on the advance of knowledge to resolve current problems (e.g. basic science about COVID-19) with the ability to engage in incremental as well as disruptive innovation challenges in networks that combine academic perspectives with the innovation needs of businesses and public agencies (e.g. the development of vaccines and treatments to contain the

spread of COVID-19). These linkages increase not only the generation of knowledge but also the probability of transfer to both the productive and social sectors. A university that is called upon to interact, co-create, and achieve far-reaching impacts on regional, national, and global development has been termed a 'Fourth Generation University' (Pawlowski 2009) – an approach that in recent decades has focused on the function of universities within innovation ecosystems and their entrepreneurial role (Lawton Smith and Leydesdorff 2019). Thus it can be argued that universities are crucial agents within their close geographical environment, due to their integration into regional innovation systems and their ability to produce, transfer, and co-create technological and scientific knowledge. Given that innovation is broadly agreed to be a crucial factor for productivity and economic growth, attention is increasingly being paid to the various forms of collaboration among agents as prominent and efficient ways to foster innovation. In fact, the search for new sources of knowledge, skills, and strategic partners reflects the very popular concept of open innovation (Chesbrough 2006) made possible by interactions between actors in the realization of scientific and technological research projects, consulting projects, and even the generation of patents by inventors from distinct institutions (OECD 2013).

This potential positive effect explains the growth of instruments that facilitate collaboration, such as the creation of technology-based companies founded from university activity, the participation of companies in R&D activities, the co-funding of patents, and other scientific research and technological projects. Universities can also encourage their researchers to apply for patents, taking full advantage of the knowledge developed from experiments undertaken within the institution. Rubiralta (2004) emphasizes the role of collaboration between groups of inventors (mainly from universities and technology centres, but also with companies located in prominent geographical areas) in order to promote regional innovation. Collaborative innovation is therefore a practice that will likely remain a key element in optimizing the combination of capabilities among different actors and fostering the generation of technologies that are highly complex.

All of these mechanisms permit increasing collaboration among universities, companies, and entities from both the public and private sectors, and this takes place in diversified geographies that include both national and foreign organizations. The geography of relationships and the combination of linkages differ from one instance to another, because collaboration can occur in national or international contexts; and this aspect was noted in the Archibugi and Michie's (1995) description of the internationalization of technology. However, this has been less recognized in the literature on technology transfer or under the systems of innovation and triple helix approaches (Carlsson 2006; Lawton Smith and Leydesdorff 2019). Some critics to these approaches point out that interaction dynamics among institutional agents are context-specific; but these interactions are increasingly taking place across national borders (Cai and Etzkowitz 2020).

Given this, our conceptual proposal is that the process of knowledge transfer implies the consideration of reciprocity in flows, because the relationship between a university and its environment is not unidirectional but must be analyzed from at least two directions and dimensions: in terms of what the university receives from and gives to its local environment, and in terms of the geography of knowledge-sourcing. In this sense, the activity of a university and its ability to influence its local system is linked to social, productive, and political characteristics (Uyarra 2010; Kempton 2019), all of which are

location-specific. On the other hand, collaboration linkages can be developed with actors beyond local borders. Thus the internationalization of universities can also foster knowledge transfer, which can in turn have positive impacts on local environments (Petruzzeli & Murgia, 2020). This argument finds support in the tradition of global innovation networks that connect geographically dispersed knowledge, taking into account that most evidence has been gathered from the perspective of multinational enterprises while underlining the role of personal relationships (Cano-kollmann, Hannigan, and Mudambi 2018). Therefore, it is plausible to include within the analytical framework both knowledge from universities and connections among academics.

It should be noted that processes of knowledge generation and transfer further require the consideration of instruments that stimulate and facilitate them, including research contracts, consulting activities, licensing, mobility of human resources, patents, and the creation of spin-offs. Accordingly, Fuster et al. (2018) empirically confirmed that university spin-off companies are major players in the entrepreneurial university ecosystem and contribute to strengthening knowledge transfer through their relationships with other companies well beyond the university environment. Furthermore, the presence of interface infrastructures (such as technology transfer offices and science parks) and a local concentration of high-tech companies may have a positive impact on the commercialization of university research and technological results (Caldera and Debande 2010). Since university performance is conditioned by regional differences, more evidence is always welcome, and this paper contributes in that direction.

2.2. University patents as a mechanism of knowledge transfer

Patents are a valuable source of information on technological progress, and they are also used as an indicator of international collaboration (Griliches 1990; Patel and Pavitt 1997; Patel and Vega 1999). As stated in a report entitled 'Boosting Open Innovation and Knowledge Transfer in the European Union' (European Commission 2014), more actions should be adopted to strengthen the role of universities as key institutions in European innovation ecosystems that interact with other partners for knowledge co-creation. This proposal is justified by the internal transformations occurring within universities as well as their current conception as centres for knowledge diffusion and their activity as intermediaries in the commercialization of science and technology.

The main references on patent regulation in universities at the global level is the Bayh-Dole Law enacted in the United States in 1980, focused on the identification of inventions derived from research supported by public funding. Following the U.S. example, certain European countries adapted their regulatory frameworks in the late 1990s to provide more autonomy to universities in activities related to intellectual property and interactions with public and private-sector entities (Rafferty 2008; Mowery and Sampat 2005). In fact, the relevance of patents granted by universities has been gaining momentum.

Several studies related to university patents have been conducted for European countries (Geuna and Nesta 2006; Azagra-caro 2014; Cesaroni and Piccaluga 2005; Acosta, Coronado, and Martinez 2012). For instance, an analysis of patents in Finland concluded that most inventions had close ties to scientific research and were very frequently financed by public funds (Meyer, Siniläinen, and Utecht 2003). Saragossi and

Pottelsberghe (2003) found that a higher propensity to patent was further due to more effective technology transfer offices in Belgian universities, as well as to the fact that universities with relatively strong performance in patenting often filed their patent applications jointly with specialized government-sponsored research centres. Coupé (2003) focuses on the amount of resources spent on research and its positive impact on university patents in the EU, finding that elasticities are similar to those of commercial firms. Regarding collaboration networks, Balconi, Breschi, and Lissoni (2004) analyzed academic patents, arguing that networks of inventors are highly fragmented in Italy, except in certain technological fields where science plays an important role. In this line, Baldini (2006) focused on Danish universities and noted the importance of developing a regulatory framework that helps to remove obstacles to research collaborations among institutions.

In Spain, Gonzalez, Manglano, and Zulueta (2007), taking patent applications from Spain's Office of Patents and Trademarks (OEPM) between 1980 and 2000, found that the participation of universities in the national patent system was very limited and marked by institutional dispersion. Elsewhere, Fernandez et al. (2009) looked at 47 Spanish universities to estimate determinant factors in the development of patents; their results show that the larger the research group, the better the research quality, and the greater the experience around technological transfer, the higher the likelihood of successful patenting. More recently, Martínez and Bares (2018) used patent data corresponding to public universities in the region of Andalusia as a valid indicator of technology transfer activity from academic institutions in the period 1998–2009, showing that the further a university patent extends into internationalization, the more likely it will be transferred to a private company.

3. Methodology

3.1. Gathering university patent data

Statistics derived from patents are very useful as indicators of knowledge generation and transfer, and they have been widely used in works of social research due to the large amount of data available and the levels of industrial, organizational, and technological detail they provide (Griliches 1990). Patents have also been taken as events in the three-dimensional space of triple helix interactions (Leydesdorff 2010); while patents are output indicators for science and technology, they also function as inputs into the economy (Lawton Smith and Leydesdorff 2018). Nonetheless, patent data are complex, and patent databases have their own advantages and disadvantages that must be carefully considered prior to use.

The analysis of patents granted by the USPTO carried out here implies two main requirements in data-gathering: first, it includes patents with at least one inventor from Spain; and second, at least one assignee must be a Spanish university. The USPTO database contains relevant information, the complete patent text, and useful metadata. While the likelihood of patenting in a foreign system varies, and depends on many factors, it is agreed that the most valuable inventions tend to be patented in the most important patent systems, like the USPTO (Archibugi and Coco 2005).

The online USPTO database (PatentsView) contains patents granted since 1976. However, the participation of Spanish inventors and/or organizations from universities with patent activity dates mainly from the 1990s; thus we chose to limit this study to patents granted between 1990 and 2017. From those patents, we identified 462 crediting at least one Spanish university. This number is favourable when compared with Gonzalez, Manglano, and Zulueta (2007), who found 1,251 patents granted to Spanish universities by Spain's OEPM between 1980 and 2000. Participation in the national patent system by universities is thus revealed as relatively modest – coincident with their low propensity to patent in the USPTO. It is also important to consider that the connectedness between Spanish universities and their innovation networks may span across multiple countries, and collaborative ties with agents located around the world are more likely captured by USPTO patents than through local Spanish patents.

The USPTO database includes information on all the inventors and assignees of each patent, their countries of origin, and relevant bibliographic information. While we considered all the patents granted, special attention is paid to those involving co-inventions (where a team rather than an individual was responsible for the invention). Co-inventions have been used elsewhere to explore collaboration patterns (Ejermo and Karlsson 2006). According to Cano-kollmann, Hamilton, and Mudambi (2016), the existence of knowledge networks between regions or countries responds to the fact that organizations search for knowledge that is not available in their own territory. Regarding collaboration, and considering that a patent may have multiple assignees or inventors, the order of assignees or inventors is not relevant here.

To study collaborations, we divided patents in two groups: 1) national patents, involving inventors and assignees from Spain only; and 2) international connected patents, or any patent with the participation of foreign inventors or assignees. The Spanish regions involved in patents were also identified, along with the foreign countries in the case of international connected patents. Further, we determined whether collaboration took place with public research centres, private companies, or other universities.

3.2. Econometric model

The following econometric model is defined to identify the principal factors explaining patent applications from Spanish universities and, consequently, their performance in the generation of technology capable of being transferred to industry and society. The analytical objectives are to determine the role played by collaboration and what sort of interactions are performed, considering both the geography of networks and the types of agents with whom universities collaborate. It is also assumed that collaboration is often conditioned by knowledge-based R&D projects and contracts signed between universities and other entities:

$$\begin{aligned} PAT_i = {} & \beta_0 + \beta_1 COL\_NAT_i + \beta_2 COL\_INT_i + \beta_3 COL\_PUB_i + \beta_4 COL\_PRIV_i \\ & + \beta_5 RD\_COL_i + \beta_6 RD\_CONT_i + \beta_7 RPROJ\_NAT_i + \beta_8 RPROJ\_EU_i \\ & + \beta_9 SCIENT\_PROD_i + \beta_{10} REGION_i + u_i \end{aligned} \quad (1)$$

The dependent variable (PAT_i) is the cumulative number of patents granted by the

USPTO to university *i* until 2017. This is taken as a proxy for the universities' innovative performance and their knowledge transfer.

The main independent variables capturing the effect of collaboration in the innovative performance are grouped into two dimensions. The first refers to the geographical scope of networks for the generation of new knowledge, differentiating between national (COL_NAT_i) and international (COL_INT_i) collaboration. These two regressors are dummy variables that adopt the values 1 (if the university collaborated with other inventors) or 0 (if not); this represents the mean effect of national and international networks. It has been highlighted that knowledge transfer networks may favour innovation capabilities and technology transfer, with special relevance to differentiation between local and international partnerships, the former being more significant due to geographical proximity (Ortega 2011).

The second dimension that characterizes collaboration in patent networks is the type of agent with whom a university collaborates, including public research centres (COL_PUB_i) or private companies (COL_PRIV_i). These regressors measure the number of collaborations with each of these entities in order to capture the intensity effect of open innovation in Spanish universities. Disentangling the effects of public and private partnerships is important, since collaboration between academic institutions and private organizations is usually more effective in reaching the patenting stage and also in promoting knowledge transfer due to access to external sources (Mohnen and Hoareau 2003).

In line with this argument, we included in the model two more independent variables related to collaborative and contractual R&D funding: RD_COL_i and RD_CONT_i, respectively. Collaborative R&D projects are developed jointly between universities and companies through the formation of consortia, while contractual funding includes research contracts, agreements for technical advice, and other services contracted by companies and other agents. These collaboration relationships and agreements may increase knowledge-based interactions among firms, national research centres, and universities that impact positively on the generation of new knowledge (Lawson 2013; Azagra-caro, Carayol, and Llerena 2006).

It is also important to control for the R&D that universities receive from precompetitive and subsidized research projects involving basic and applied research. These R&D funds are key in Spain's science and technology (S&T) policy, as well as in the EU research strategy supporting the incentive structure to promote project-based R&D networks (MEC 2011; European Commission 2011). Publicly supported R&D projects contribute to expanding the geography of collaboration networks within and beyond borders, stimulating new knowledge as well as its diffusion and transfer (Scherngell and Barber 2011; Fritsch, Titze, and Piontek 2020). For this reason, we included in the model two regressors that reflect the public R&D funds received by Spanish universities from the State and from the European Union ($RPROJ\_NAT_i$ and $RPROJ\_EU_i$, respectively).

Another aspect of the university as a crucial agent in both national and regional systems is its scientific production. It has been stated that the higher the research quality of a university, the greater the impact will be on innovative performance, under the expectation that higher levels of patenting and technology transfer can be achieved (Fabrizio and Di Minin 2008; Caldera and Debande 2010). One proxy of the

scientific quality of universities is the number of publications in the ISI Web of Knowledge (Acosta, Coronado, and Martinez 2012). Accordingly, we included in the model an independent variable that captures the number of articles published in the Web of Science ($SCIENT\_PROD_i$).[2]

Finally, the geographical location of Spanish universities is explicitly included in the analysis to control for regional innovative capabilities. Universities embedded in highly innovative contexts (where firms are highly innovative) tend to perform better in terms of both technology transfer and patenting activity (Friedman and Silverman 2003; Berbegal-mirabent, Lafuente, and Solé 2013). Given the heterogeneity of technological development of the various Spanish regions, we included a dummy variable that takes a value of 1 if the university is located in a highly innovative context and 0 otherwise ($REGION_i$). Highly innovative regions are defined based on the number of technologically innovative firms and the R&D expenditure in high technology industries. Valencia, Madrid, Catalonia, and the Basque Country are the most innovative regions according to the indicators of the Spanish S&T system elaborated by the Spanish Observatory for R&D (FECYT 2019): these concentrate more than 60% of innovative firms located in Spain and almost 74% of the R&D expenditure in high-tech industries. Appendix 1 shows a description of the variables.

3.3. Estimation procedure

The characteristics of the dependent variable are crucial for choosing the most appropriate technique for the estimation. Considering that patents can only adopt non-negative integer values, a standard linear assumption is not appropriate; count data methods, and particularly the Poisson regression model, are more relevant for the analysis of patents. The most critical assumption of the Poisson model for obtaining asymptotically efficient estimators regards the distribution of the dependent variable, with the imposition that the conditional mean equals the conditional variance. This assumption is frequently violated in applications, because patent data tend to be characterized by over-dispersion. In such cases, the negative binomial regression model is the most appropriate technique, adding a random parameter to the Poisson specification that accounts for individual unobserved heterogeneity (Cameron and Trivedi 1998).

Another important aspect for the selection of the estimation procedure is the large number of zero observations for patent counts (almost 43% of Spain's universities report 0 patents granted by the USPTO). Zero-inflated count models permit differentiation between a process generating zero values and a process that generates positive values. These models combine a qualitative regression that explains the probability of observing zero as an outcome through a logit model and a quantitative regression that explains the count outcomes through either a Poisson or negative binomial model.

For the first stage of the zero-inflated model – the qualitative regression – we control for the university scientific base, proxied by publicly R&D funds received from the State and the European Union ($RPROJ\_TOT_i$) and by scientific production ($SCIENT\_PROD_i$), given that previous findings highlight the relevance of the scientific base in the quality of patents (Gittelman and Kogut, 2003; Caldera and Debande 2010) and, consequently, in the propensity to obtain more valuable patents in the most important patent offices.

For the second stage, the α-Likelihood Ratio test allows determination of whether the zero-inflated negative binomial model (ZINB) is more appropriate than the zero-inflated Poisson model (ZIP) because of the over-dispersion of the dependent variable. In our estimations, the null hypothesis is rejected, prompting us to apply the ZINB model. Moreover, the results of the Voung test to select between the ZINB and the negative binomial indicate that the ZINB model is preferred because of the excess of zeros in our sample. It also has another advantage related to the fact that the zero-generation process could be the result of those universities that have never made patent applications, or those universities that have done so but not at the USPTO. This methodology allows us to control for this possible misspecification bias.

4. Analysis and discussion of results

4.1. A brief description of university patents

Spanish universities have not enjoyed a long tradition in application for patents at the international level, but there has been a notable growth over the past three decades. Among the USPTO patents from the 1990–2017 period, 462 patents have at least one Spanish university among the assignees. Figure 1 shows the number of patents granted per year. While the quantity was observably marginal during the 1990s, patents increased significantly after 2000, following a positive and increasing trend over the past decade with a particular uptick since 2012. This upward trend is coincident with favourable changes in the regulatory framework of Spanish universities, which allowed great advances in the Spanish R&D system. Nevertheless, the number of patents granted to Spanish universities remains below that of other countries and especially the most technologically advanced universities, such as in the U.S. (Henderson, Jaffer, and Trajtenberm 1998; Mowery et al. 2001). Technology transfer from university to industry is

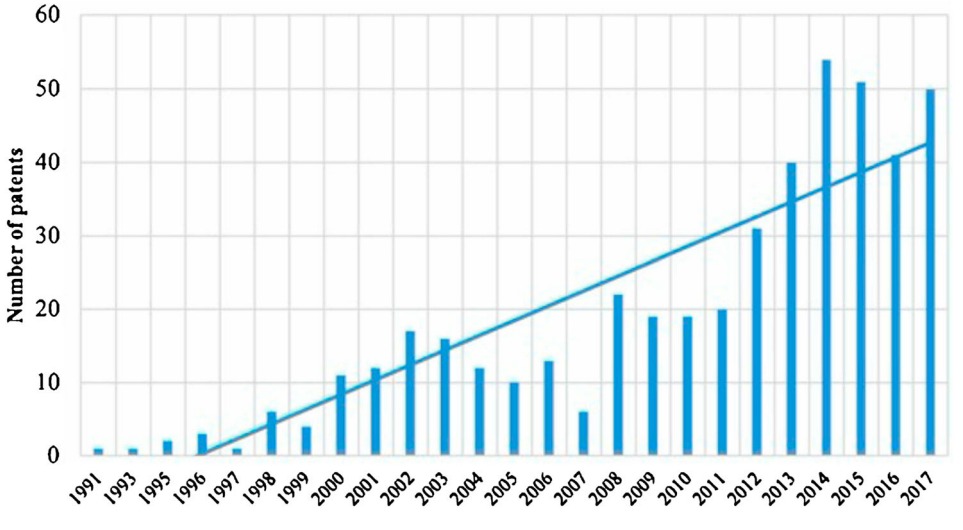

Figure 1. USPTO patents granted to Spanish universities, 1990–2017. Source: the authors, based on data from the USPTO.

another aspect in need of improvement in Spain, and this deficiency can be partly explained by the structural characteristics of the Spanish innovation system itself. In fact, Spain is positioned in the 'moderately innovative' group, ranking 16th among the EU-28 countries (European Commission 2018).

Regarding the distribution of the university system in Spain, there are 84 universities, which implies a ratio of 1.8 universities per million inhabitants (MEC 2016). Public universities are dominant in the system: there are 50 public and 34 private universities. Only 36 universities were granted patents by the USPTO in the period of analysis, and among these approximately 89% were public. Figure 2 shows the top 10 universities ranked by the number of patents granted. Regarding the geographical distribution, concentration is high because just three regions (of 17) concentrate more than 60% of national patents. Half of these come from Valencia (33%), followed by Madrid (18%) and Andalusia (11%). A study conducted by the OEPM on university national patents between 2005 and 2017 shows a pattern similar to that already described but even more regionally concentrated, where Andalusia and Madrid account for almost 45% of total patent applications (22.5% and 21.6%, respectively), followed by Catalonia (12.5%) and Valencia (10.7%) Regarding the top 10 universities ranked by the number of national patent applications, the Polytechnic University of Madrid came in first, followed by the Polytechnic University of Catalonia and the University of Seville, all with more than 400 patents. The similarity of results between the OEPM analysis and our own suggests that the geographical location of the university influences the ability to efficiently carry out knowledge transfer (Baldini, Grimaldi, and Sobrero 2006), along with characteristics such as the presence of biomedical and engineering faculties (Caldera and Debande 2010). However, it must be clarified that Spanish universities are highly diversified in their knowledge specialization, and 94.4% of universities patenting at the USPTO feature a polytechnic and/or a biomedical school.

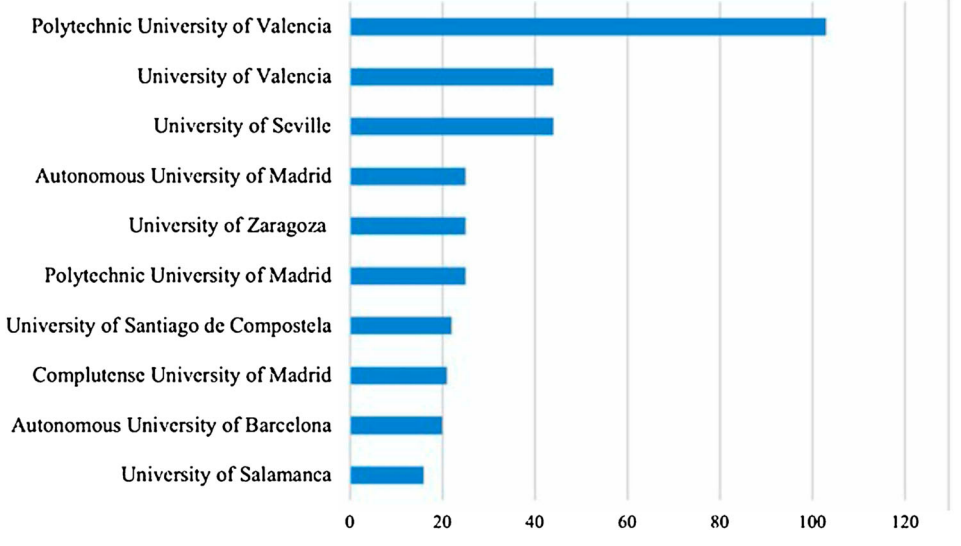

Figure 2. Top 10 universities, ranked by the number of USPTO patents granted. Source: the authors, based on data from the USPTO.

Assuming that collaboration by universities with other actors of the innovation system is an essential aspect to strengthening knowledge transfer, it is noteworthy that the majority of patents granted by Spanish universities are national. Meanwhile, those patents that involve an inventor or assignee from abroad (denoting international collaboration) represent less than 20% of university patents. Among the national patents, 233 have no assignee beyond the university itself, while 148 have at least one additional assignee (thus sharing the patent ownership). This distribution differs across universities, although there is a positive relationship between those universities that collaborate with other agents and those with a high number of patents.

Regarding the distribution of collaboration entities by type, restricted to national patents, the Spanish National Research Council (CSIC) is the main collaborator, being involved in 63% of the total number of collaborations. This is the largest public research institution in Spain and the third largest in Europe, and its importance in Spanish patents is not surprising, demonstrating how public investments in R&D are translated into collaborations, innovations, and patents. The second most important type of collaborator has been private companies (19%), the involvement of which is closely related to R&D activities. Meanwhile, collaboration with other universities represents only 4% of collaborations, with the remaining 14% going to public administrations, foundations, and other research centres.

The international collaboration in patents by Spanish universities reflects the degree of connectivity and how knowledge transfer takes place among inventors or assignees in different countries. Figure 3 shows the distribution of foreign inventors and assignees by regions, revealing that Spanish universities collaborate mainly with inventors from Europe and the United States.

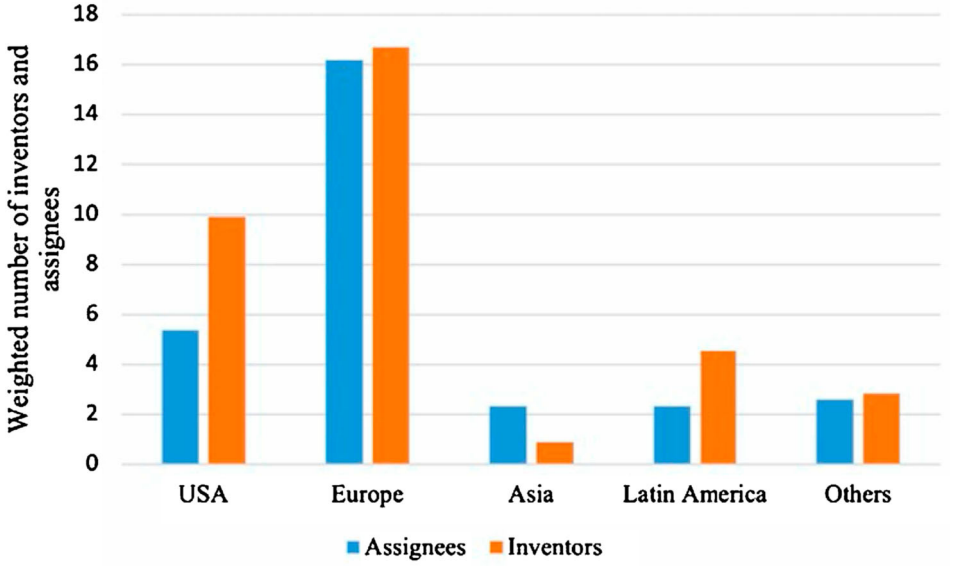

Figure 3. Distribution of USPTO patents granted to Spanish universities, based on the place of origin of foreign inventors and assignees, 1990–2017. Source: the authors, based on data from the USPTO.

Geographical proximity seems to be a favourable aspect for the extension of greater international collaboration linkages with 'closer' agents within the European region, and this is clearly reinforced by R&D policies promoted by the EU. Scientific and technological cooperation, geographical mobility, and exchange of researchers are all significant funding activities with the goals of improving European capabilities and confronting economic and social challenges. In fact, the most recent strategy (Europe 2020) is explicitly aimed at strengthening links between education, business, and research to facilitate the consolidation of a 'Union for Innovation'.

One interesting issue is to try to disentangle whether the differences between assignees and inventors are due to how the patenting networks are shaped in different contexts. We find that some assignees from Belgium, Germany, the Netherlands, and France include companies and universities together (example: NanoMegas SPRL, Ghent University, Buck-Chemie GmbH, University of Twente, Radboud University, Joseph Fourier University and Strasbourg University). Collaboration linkages with the United States, on the other hand, predominantly include companies (example: Inspire Pharmaceuticals, Flow Focusing, Siemens Medical Solutions, GWR Instruments, and Georgia Tech Research Corporation). Even so, collaborations among universities do occur, as with the University of Kentucky Research Foundation and the University of Connecticut. These linkages may be explained by the U.S.'s pioneering role in many new technologies, as well as the fact that it enjoys recognition as the world leader in technological innovation. Accordingly, networks of international collaboration between Spanish universities and other agents of the international context are mostly framed by co-invention patents with participation by foreign companies and universities.

4.2. Econometric results

The results of the model estimation are shown in Table 1. Diverse patterns of collaboration emerge when universities patents are analyzed. In particular, the dominant pattern of collaboration is characterized by the significance of public-private partnerships in university patents, also describing a geographically diverse map defined by both national and international linkages.

Our analysis shows the combination of factors that make more likely the innovation function of universities in the configuration of local innovation ecosystems. In particular, Table 1 shows that the estimate corresponding to the variable of collaboration between universities and companies is statistically significant and has the expected positive sign, and this is also true for the collaboration between universities and public research centres. However, the marginal effect of private collaboration is relatively higher, practically doubling the effect of public collaboration on the patenting activity of Spanish universities. Although they tend to establish more linkages with public research centres than with private companies (as mentioned above), the estimation results confirm the greater effectiveness of relationships between academic institutions and companies in the generation of patents. Assuming that patents are a good indicator and predictor of innovation performance, this result leads us to affirm that this is also a favourable factor in the processes of knowledge generation and transfer to the productive system.

The establishment of both national and international relationships in the generation of patents is also significant, with notable differences in their marginal effects. In

Table 1. Estimation Results.

	Coefficient-Marginal effects (dy/dx)
COL_NAT (†)	2.701
	(0.6427)***
COL_INT (†)	5.6744
	(1.2943)***
COL_PUB	0.1062
	(0.0206)***
COL_PRIV	0.2191
	(0.1292)*
RD_COL	−0.6897
	(0.4419)
RD_CONT	−1.2612
	(0.9866)
RPROJ_NAT	0.9062
	(0.4311)**
RPROJ_UE	0.6966
	(0.4148)*
SCIENT_PROD	0.5958
	(0.9316)
REGION	−1.3566
	(0.9175)
Constant	–
Inflate	
RPROJ_TOT	−0.0173
	(0.0022)***
SCIENT_PROD	−0.0859
	(0.0109)***
Wald χ^2	710.20***
α-Likelihood Test	11.72***
Voung Test	1.72**
Num. Observations	58

Robust standard errors in parenthesis.
* Significant at 10%; ** significant at 5%; *** significant at 1%.
(†) Marginal effects represents the change in the dummy variable from 0 to 1.

particular, results corresponding to these variables indicate that those universities that establish national collaborations are able to achieve (on average) almost three more patents than those universities that do not engage in such a network. Meanwhile, when collaboration takes place at the international level, such networks generate an effect that doubles the propensity to patent. Although previous studies show that the proximity factor is more relevant in the innovative and knowledge transfer capacity of universities, the results presented here highlight the relevance of international connectivity, because the importance of the interaction with partners across countries is greater; and this result is in line with recent evidence based on the Spanish region of Andalusia (Martínez and Bares 2018). The interpretation of this result finds support for the relevance of global innovation networks to connect knowledge that was originally distant and disperse. Although this topic has been explored in the MNE literature (as referred to in section 2), it may be extended to universities as well.

This argument is reinforced by the effect of other factors controlled in the model, as can be specifically appreciated in relation to the sources of funding for R&D activities carried out by Spanish universities; the effects of Spanish and European funds allocated to research projects on the generation of new knowledge are both statistically significant. Although national funds have an observably greater effect, this is only 0.2 percentage points above the European funding. On the other hand, collaborative R&D projects

carried out with companies and contracts for R&D activities have no significant effect, which would suggest that technology transfer mechanisms are not as developed here as when other types of interactions occur.

Unlike what has been found in previous contributions, scientific production does not seem to influence the propensity of Spanish universities to patent, as this variable is not statistically significant; a similar result was recently found in Rizzo and Ramaciotti (2014) for the case of Italy. However, as shown in the inflation part of the model, the scientific base of the university exerts a clear negative and significant effect in the probability of not registering patents at the USPTO – especially in terms of scientific production; the marginal effect is relatively higher than that associated with public R&D funds. Similarly, the region in which a university is located is found to be not relevant, which allows us to affirm that despite the high heterogeneity in innovativeness among the Spanish regions, the existence of public-private linkages and insertion in collaborative networks of varied geographies are more important than the location. These results may be linked to the relative strength of the crucial dimensions adopted in the definition of regional policies for consolidation of the innovation ecosystems.

These findings confirm our conceptual approach that highlights the role of universities in orchestrating the process of knowledge generation and transfer. This is a complex process conditioned by a combination of factors that allow us to underline complementarity in collaboration, due the different types of agents as well as the relevance of geographical diversity, taking into account both national and international connections in the evolution of collaboration networks. Thus, the contribution of universities to the dynamic evolution of local innovation systems is found to be more likely.

5. Concluding remarks

This paper considers the role of collaboration in the ability of universities to transfer knowledge to industry and society in favour of local innovation ecosystems, and it goes a step further toward understanding the relevant linkages and their geographical scope. Based on patent data for Spain, we provide new evidence on the role of national and international collaboration networks for the innovative performance of universities. The complexity of contemporary technological solutions implies that the concept of 'one-way science and technology transfer' has lost momentum in favour of interactions and multiple relationships among different agents. It is therefore plausible to affirm that universities tend increasingly to forge relationships that can better (and more efficiently) potentiate their contributions to economic and social development. These arguments support the fact that universities create effective mechanisms for knowledge dissemination to the productive and social fields, thus enhancing the local systems of innovation. Universities can also develop new abilities to coordinate diverse knowledge-sourcing, as favoured by the rapid evolution and expansion of digital technologies. A deep knowledge of intellectual property rights is therefore as crucial as the assumption of a leadership role within the local environment.

This paper analyzes the processes of knowledge generation and its potential transfer through the patenting activity of Spanish universities, further considering the relevance of the regional context. Although it is verified that innovative activity is highly concentrated into just a few Spanish regions, it must also be noted that universities differ individually in their potential to contribute significantly to the generation of knowledge, and

this is largely explained by their linkages with the productive sector. Meanwhile, international collaboration in university patents reflects the role of connectivity for better transfer of scientific and technological knowledge between inventors and organizations across countries – an aspect that may revert positively to the local environment. Our findings confirm that the pattern of Spanish university patents is defined by a combination of factors including private-public partnership and a geographically diverse map of interactions. Collaboration with companies is more relevant for patenting activity than collaboration with public institutions. Nevertheless, international connections are dominant over national linkages as well as over the type of partnership.

Overall, it can be argued that the impact of knowledge transfer will ultimately depend on the capabilities of universities to generate linkages and to manage them in an articulated manner with different agents, in both national and international contexts. Accordingly, it is important to highlight the relevance of fostering and strengthening relationships between universities and the business sector, which would expand the transfer mechanisms for science and technology – essential to finding responses to many of our current social and environmental challenges (such as digitalization or the sustainable development goals). In this sense, a regulatory framework for innovation policies is necessary to establish appropriate instruments and infrastructures that will facilitate collaboration capable of enhancing knowledge transfer.

Finally, although we have addressed our research questions, we encountered certain limitations that invite further research on the topic. We would benefit from further examination of implications, or of which initiatives might reinforce the articulation capacity of universities, particularly in regions that underperform in innovation. Diversity and complementarity describe a complex set of collaboration linkages resulting from a cumulative evolutionary process that may ultimately benefit knowledge transfer from universities to industry and society. However, a deeper analysis is still needed to integrate dynamics into the analysis of the two coexistent dimensions, as this would permit a more grounded argument about the reciprocity of knowledge flows (for instance, the extent to which one of the dimensions can be understood as a driver of the other, or whether international collaboration can enhance stronger collaboration with one particular type of agent or another).

Notes

1. A good example is the Spain's Organic Law of Universities of 26 December 2001 (BOE-A-2001-24515. https://www.boe.es/eli/es/lo/2001/12/21/6).
2. Information of collaborative and contractual R&D funding, project-based R&D funds, and scientific production was obtained from the annual reports of RedOTRI, the network of TTOs in Spanish universities and public research organizations.

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Appendixes

Appendix 1. Definitions of variables.

Variable	Definition	Source
PATi	Total number of patents granted, university *i*	USPTO
COL_NATi	Collaboration with national agents in patents granted, university *i*, dummy variable (1 yes; 0 no)	USPTO
COL_INTi	Collaboration with foreign agents in patents granted, university *i*, dummy variable (1 yes; 0 no)	USPTO
COL_PUBi	Number of collaborations with public research organizations in patents granted, university *i*	USPTO
COL_PRIVi	Number of collaborations with private companies in patents granted, university *i*	USPTO
RD_COLi	Logarithm of the total funds from collaborative R&D projects (in euros) divided by the teaching and research staff, university *i*	RedOTRI
RD_CONTi	Logarithm of the total funds from R&D contracts (in euros) divided by the teaching and research staff, university *i*	RedOTRI
RPROJ_NATi	Logarithm of the total funds from R&D competitive projects financed by the Spanish State (in euros) divided by the teaching and research staff, university *i*	RedOTRI
RPROJ_EUi	Logarithm of the total funds from R&D competitive projects financed by the European Union (in euros) divided by the teaching and research staff, university *i*	RedOTRI
SCIENT_PRODi	Logarithm of the number of articles published in the Web of Science divided by number of teachers and researchers, university *i*	RedOTRI
REGIONi	Region where university *i* is located, dummy variable (1 if in an innovative region; 0 if in a non-innovative region)	FECYT

Appendix 2. Descriptive statistics.

Variable	Mean	Std. Dev./Mean	Min.	Max.
PAT	7.25	2.13	0	102
COL_NAT	0.33	1.43	0	1
COL_INT	0.37	1.33	0	1
COL_PUB	1.63	4.50	0	57
COL_PRIV	0.97	2.46	0	11
RD_COL	1811.30	1.27	0	12696.72
RD_CONT	3316.99	1.43	52.34	36185.97
RPROJ_NAT	3323.40	0.92	0	18824.72
RPROJ_UE	1780.35	1.23	0	12828.32
SCIENT_PROD	0.56	0.53	0	1.41
REGION	0.49	1.02	0	1

All variables are in levels.

Appendix 3. Correlation matrix.

	PAT	*COL_ NAT*	*COL_ INT*	*COL_ PUB*	*COL_ PRIV*	*RD_ COL*	*RD_ CONT*	*RPROJ_ NAT*	*RPROJ_ UE*	*SCIENT_ PROD*	*REGION*
PAT	1										
COL_NAT	0.5332	1									
COL_INT	0.5425	0.5129	1								
COL_PUB	0.8740	0.3119	0.2771	1							
COL_PRIV	0.6186	0.5366	0.5263	0.3284	1						
RD_COL	0.1497	0.097	0.1392	0.1377	0.2085	1					
RD_CONT	0.2869	0.3028	0.3123	0.1900	0.2509	0.598	1				
RPROJ_NAT	0.2767	0.2805	0.1647	0.1907	0.2529	0.4082	0.5713	1			
RPROJ_UE	0.1072	0.1083	0.1193	0.0738	0.1755	0.5171	0.5304	0.3604	1		
SCIENT_PROD	0.2431	0.2921	0.339	0.1136	0.2676	0.2726	0.6444	0.6717	0.5189	1	
REGION	0.1287	0.1123	0.111	0.1361	0.2147	0.0286	0.0243	−0.1256	0.1454	−0.1913	1