The Production of Academic Technological Knowledge. An Exploration at the Research Group Level

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Abstract

Public research institutions have a key role in a knowledge-based society as they lead scientific research, and generate patentable technology directly applicable to industrial productive processes. In this paper, we address the latter role. Several well-known papers have dealt with the production of university patents at the level of universities and laboratories; however, despite the relevance of research groups in national research systems, their capacity as producers of patents has been neglected. In this paper, we fill this gap by testing the effect of previous collaborations and the scientific background of the group on the production of knowledge, measured by the number patents. In the framework of a knowledge production function, we estimate several empirical count models with a sample of 1,120 research groups affiliated to the three major public research institutions in Spain. Our findings suggest that the production of patents at the research group level is positively and significantly correlated with the variables capturing private collaboration and scientific background. The results also point to significant differences in the production of technological knowledge across institutions and areas of research.

Keywords: collaboration, knowledge production function, patents, research group.
JEL Classification: O31, O38, C21.

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1. Introduction

Public research institutions have a key role in the knowledge-based society as they lead scientific research and generate patentable technology directly applicable to industrial productive processes (D'Este and Perkmann, 2011). Furthermore, research universities have become the foundation for successful technology commercialization as well as boosters of the regional economy (Carayannis et al., 2015; Marozau et al., 2016). The objective of this paper is to explore the production of technological knowledge by using patents as indicator, but unlike most extant analyses of academic patenting that focus on the university level, we follow a latest strand of literature that consider the factors affecting the production of university outputs at the level of research group (e.g. Olmos-Peñuela et al. 2014, Aguiar-Díaz et al., 2016; Hormiga et al., 2017; Barletta, 2017). A research group is defined as group of people, scientists and non-scientists, which works for a certain time period to produce new knowledge. The group is a relevant part of a larger organisation (university, department, etc.) and at least some of its members are employed by a university. Also, The team is recognized from outside as a separate entity (Barjak and Robinson, 2007).

Our interest in research groups as units of analysis is supported on several grounds. First, the groups are the key knowledge producing organizations within national science systems, and they are a reference when research and development (R&D) performance is evaluated (Barjak and Robinson, 2007; Vabo, et al., 2016; Ramos-Vielba et al., 2016). Second, in the last few decades, knowledge production has been increasingly developed within groups or teams of scientists. For example, the allocation of public research funding was traditionally through individual academic scientists; nowadays, competitive project funding has grown considerably and there is a greater emphasis on fostering organized research centres, networks, and interdisciplinary teams (Henze et al., 2007). In this respect, Etzkowitz (2017), points out that we are witnessing a shift in the center of academic gravity from departments of individual scholars to networks of research groups, particularly to capture larger funds. Third, a better understanding of the factors that exert an influence on groups engaged in technologically creative work has important policy implications. For instance, Etzkowitz (2003) argues that the internal organization of research universities comprises a series of research groups with firm-like qualities, especially under conditions where research funding is awarded on competitive bases.

Our contribution focuses on two main issues. First, this paper fills a gap in the research on patent production at the research group level. Despite their importance in regional and national research systems for both the production of knowledge, and as the basic unit for distributing public funds, the role of the research group as producer of patented technology has been neglected. Most of the previous research has identified the factors affecting the production of patents at the level of universities, laboratories and regions (Azagra-Caro et al., 2006; Lawson 2013; Romano et al., 2014; Coronado et al., 2017). Although there are some recent papers that stress the role of the research group in producing scientific outputs (Olmos-Peñuela et al. 2014; Hormiga et al., 2017) and some transfer activities (Aguiar-Díaz et al., 2016; Barletta, 2017), to our knowledge there is no previous research explaining the generation of technological outputs (patents) at the level of research groups. Second, we test two hypotheses with relevant policy implications. The first hypothesis centres on the role of collaboration of research groups with private companies to promote the production of patents. Testing this hypothesis would cast some light on whether there is a crowding-out effect (diverting human or public economic resources to objectives other than research) at the level of research groups. The second hypothesis refers to the extent to which the scientific background of the group hinders or encourages its production of patents. Analysing this fact is important because it would clarify whether or not scientific research and technological research are complementary outputs.

To test our hypotheses, we draw on a novel sample of 1,120 research groups affiliated to universities and other public research institutions in Spain. Our methodology relies on patent counts as an indicator of the production of innovation by public institutions. Several studies have already demonstrated that the analysis of patents is a valid and objective method for studying the processes of innovation and technology transfer (see the widely-cited survey by Griliches, 1990, and the more recent discussion by Janger et al., 2017, and Emodi et al., 2017). However, despite their known drawbacks, patent data provide a useful measure of a university's capacity to be involved in innovation and technological activities. In addition, the accessibility of this type of data enables a more extensive form of treatment than that offered by case studies or interviews (Henderson et al., 1998). Importantly, given the nature of the variable, we estimate several econometric count models to identify the main factors affecting the production of patents by research groups.

The paper is organized as follows. Section 2 includes a review of the literature dealing with the production of patents in public institutions and explains our hypotheses. Section 3 describes the data and the variables. Section 4 presents the econometric specification for testing our hypotheses. Section 5 provides the results. The main conclusions of the analysis are drawn in the final section.

2. Literature and hypotheses development

As we highlighted before, to our best knowledge, no previous empirical studies employ the research group as the unit of analysis. Therefore, we refer to several key papers dealing with the analysis of the production of technological knowledge (proxied by patent counts) in public institutions at the university and laboratory level (sections 2.1 and 2.2, respectively). These studies provide important insights into the determining factors relating to patent activity. Drawing upon this strand of literature, along with the role of collaboration and scientific background of the research group in producing patents, we propose our hypotheses in section 2.3.

2.1 The production of patents at the University level

One of the most relevant studies in this regard was by Henderson et al. (1998), who examined university patents in the US over the period 1965–88. In respect to the explanatory causes for the evolution of university patents, Henderson et al. (1998) emphasized three essential aspects: (i) the legal framework (or changes in federal laws that facilitate patent applications by universities), (ii) the increase in industrial funds destined to support university research, and (iii) the increase in the number of interface centres and institutions. In a related work, Coupé (2003) confirms the evidence on the institutional effects, combined with the significant influence of R&D expenditure. Foltz et al. (2003) also examined the production of patents in US universities, though with a focus on the agricultural and biotechnology sectors. They found strong evidence of a correlated dynamic effect in which patenting experience helps produce more patents. Payne and Siow (2003) employed data for 45 US universities. After analysing the data under different specifications, they found that when universities receive more funding, they produce more patents. Owen-Smith and Powell (2003) similarly considered the sources of the capacity for North American universities to generate results with the potential for early exploitation. They conclude that know-how, the personnel dedicated to technology transfer, the contractual links with the companies that patent, the size of the patent portfolio, the degree of association or integration in networks, and scientific publications (academic publications and the impact of university patents were directly related) were significant variables.

Outside the US, a review by Geuna and Nesta (2006) of European academic patenting concluded that the broadly defined research area of biotechnology and pharmaceuticals tended to be an area of extremely high university patenting activity. They suggested that the rapid growth of academic patenting was driven more by increasing technological opportunities in the biomedical sciences than by policy changes affecting the rights of universities to own any patents arising from publicly funded research.

Regarding the empirical literature on European university patenting and its determining factors, Saragossi and Van Pottelsberghe de la Potterie (2003) carried out a descriptive analysis of patenting activity in six Belgian universities. They attributed an increase in patents to two major changes: new technological opportunities resulting from research activities related to the biotechnology sector, and an increased propensity to patent technologies developed by Belgian universities (also related to more effective technology transfer offices). In Spain, Acosta et al. (2005) concluded that human resources, the accumulation of technological knowledge, and the business setting were key determinants in the production of university patents. In Italy, Baldini et al. (2006) showed that in the previous ten years, the number of Italian university patent applications, in Italy and/or abroad, rose substantially and that, after controlling for university characteristics, past patenting activity, and time trends, patenting activities almost tripled in universities with internal Intellectual Property Rights (IPR) regulation. In Germany, Glauber et al. (2015) found that research quality and research breadth are particularly relevant in producing patent outputs. Patenting experience, however, only appears to be relevant with respect to the technological scope of university patents.

Several additional papers have shed some light on academic patent production. Della Malva et al. (2013) analysed the effect of the Innovation Act, which was introduced by the French government in 1999 with the aim of encouraging academic institutions to protect and commercialize their scientists' inventions. Their results demonstrate a positive effect of the presence of a Technology Transfer Office (TTO), and variations between technology sectors and the size of the University. They found that the universities increased the total number of patents applied for after the adoption of internal IPR regulations. Rizzo and Ramaciotti (2014) reach the same conclusion for the case of Italy. Fish et al. (2015) analysed the determinants of university patenting from an international perspective and show that the propensity to apply for patents is very high among US and Asian universities, while European universities lag behind. In addition to the home country, further determinants of university patenting are the quantity of the universities' publications and a technological focus in areas such as chemistry and mechanical engineering. Acosta et al. (2015) support the hypothesis of diversification, which means that the production of new patents can be spurred by promoting or stimulating greater levels of technological diversification in previous periods. Coronado et al. (2017) suggest that the regional economic specialization significantly affects the production of university patents in high-technology sectors.

2.2 The production of patents at the level of laboratory/Department

In contrast to the relatively extensive literature on patents at the university level, only a few studies deal with the production of patents at the laboratory/department level. Employing a broad approach where patents were considered as both an input and an output, Azagra-Caro et al. (2003) estimated a patent production function using data on patent applications from 43 departments of the Polytechnic University of Valencia in Spain from 1991 to 2000. Their results showed that aggregate R&D expenditure had a positive effect on patents. More specifically, when R&D expenditure was split by the source of funding, Azagra-Caro et al. (2003) found that government and industry funding had a significant and positive effect on patents, and that public funding was more important for patenting than private funding. The internal characteristics of departments were also relevant in patent generation. Using a similar approach, Azagra-Caro et al. (2006) analysed patent activity in 83 active academic laboratories belonging to the Louis Pasteur University in Strasbourg. Employing count data models, they found evidence of the impact of public funding on the generation of university patents. Their results also highlighted the importance of controlling for disciplinary and institutional differences in this type of analysis. Arvanitis et al. (2008) drew on data from 202 science institutes involved in some type of transfer activity over the period 2002–04. They concluded that the main determinants influencing patenting were the presence of technology transfer offices along with the scientific field in which the institution operated ("Engineering" and "Natural Sciences" displayed a stronger inclination to patent than other disciplines). In addition, Arvanitis et al. (2008) concluded that the relevant motive for transfer activities related to the possibility of either acquiring specific knowledge from the business sector or receiving its feedback with respect to university research findings, practical experience, and application opportunities. In a very recent paper, Gurmu et al. (2010) estimated a knowledge production function for university patenting using an individual effects negative binomial model. They focused particularly on researchers in university laboratories and control for other explanatory variables including R&D expenditure, research field, and the presence of a Technology Transfer Office (TTO). Their results showed that patent output relates positively to the stock of R&D expenditure and the presence of a TTO. In addition, after distinguishing between the three kinds of researchers found in these laboratories (faculty, postdoctoral scholars, and PhD students), they found that patent counts were positively and significantly related to the numbers of PhD students and postdoctoral scholars. Table 1 presents a selection of the main studies on patent production at the level of university and laboratory.

TABLE 1 ABOUT HERE

2.3 The role of collaboration and scientific background

The literature review at the level of university and laboratory presented in the previous sections provides, from an empirical view, some clues about the factors that might affect the production of patents. Building upon this background, in this section we present our two hypotheses that focus on the role of external links between the group and private firms in producing more patents, and the extent to which the scientific experience of the group helps to generate more technological outputs, measured by the number of patents.

Regarding the first issue, the importance of collaboration relies on the idea that current knowledge and innovation processes depend heavily on synergistic interactions among R&D actors and sectors –universities and research organizations, private companies and government– (Fernández-Zubieta et al., 2016). In particular, universities can play a role in developing technology, especially pre-competitive technology, for use in the private sector (Bozeman, 2010). For example, universities can support research and development in sectors where adequate market incentives do not exist, e.g. defense, basic research in issues affecting public health (Bozeman and Pandey, 1994). Moreover, creating bridges between academic institutions and firms can benefit both organizations. Collaboration may spur universities to produce the technological knowledge demanded by companies, while firms will take advantage of the acquisition of the most recent scientific knowledge and expertise in specific technological fields (Arza and López, 2011). Arvanitis et al. (2008) also stressed this point when they argued that there is a mutual benefit from the transfer of knowledge between university and the business sector.

Most of the limited research concerning the role of collaboration with private industrial sectors in the production of more university patents favours the idea that collaboration spurs the generation of patents, at least at the university level. Owen-Smith and Powell (2003) found that contractual links with companies is an explanatory factor that may encourage the production of university patents. Miyata (2000) concluded that universities with industry–university relationships tend to generate more inventions, while Acosta and Coronado (2003), Rizzo and Ramaciotti (2014), and Coronado et al. (2017) found a significant effect of the industrial environment on university patenting. The literature on university-firm collaboration also suggests that the benefits of collaboration present differences across sectors. For example, in some disciplines such as life science, and engineering science, collaboration has a greater importance than in basic disciplines (D'Este and Perkmann 2011; Tartari and Breschi (2012). These previous findings at the university level could also hold at the research group level because research groups are basic knowledge producers within universities. These ideas provide the basis for our first hypothesis focused on the role of collaboration with firms in producing more technological knowledge:

(H1) *Scientific groups with previous external links with private companies will generate more technological knowledge*.

The discussion about the role of scientific background in producing technology goes back to one of the first (conceptual) frameworks developed for understanding this relationship, which is the linear model of innovation (See Godin, 2006, and Balconi et al., 2010, for reviews). This model puts forward the idea that innovation starts with basic research, is followed by applied research and development, and ends with the production and diffusion of innovations. Focusing on the particular role of science in producing patents, Stephan et al. (2007) provides three interesting reasons why earlier publications may be relevant for subsequent patenting. First, the results of specific research often have a dual nature in that it can often be both patented and published. Second, the increased opportunities that academic researchers have to work with industry may enhance productivity and encourage patenting. Third, the academic reward structure encourages patenting as an outcome of research.

Different alternatives to the linear model based on an evolutionary approach such as national/regional systems of innovation (Lundvall, 1992; Nelson, 1993; Braczyk et al, 1998; Acs et al., 2017), the triple helix model (Etzkowitz and Leydesdorff, 2000) and its extended versions (Carayannis and Cambell, 2009; Carayannis et al., 2018), suggest that the relationship between science and technology does not follow a unidirectional linearity. On the contrary, the flows are at least two-way (often multi-way) and the interaction is continuous. Given this complex relationship between science and technologies, the extent to which scientific advances support technological progress is unclear and there is not much systematic evidence.

Several papers have empirically dealt with this relationship at the university level. For instance, Blumenthal et al. (1996) and Powell and Owen-Smith (1998) found that in the field of life science, both organizations and individuals involved with commercialization tended to publish more, therefore a positive relationship between publication volume and patent volume was expected. However, and as pointed out by Agrawal and Henderson (2002), this relationship does not hold for all scientific fields. For example, Saragossi and van Pottelsberghe (2003) stressed the new technological opportunities resulting from research activities related to the biotechnology sector. The empirical analysis by Stephan's et al. (2007) carried out at the individual level, suggests that patents positively related to the number of publications. Azoulay et al. (2007) reached a similar conclusion that patenting behaviour is a function of scientific opportunities. Van Zeebroeck et al. (2008) concluded that the positive effects of academic patenting on research exceeded any potential negative impacts. Building on these grounds, our second hypothesis is as follows:

(H2) *The scientific background of the research group positively influences the generation of patented technology.*

3. Data and variables

To test our hypotheses, we draw on a sample of 1,120 research groups affiliated to the three main public research institutions in Andalusia, Spain: public universities, the Consejo Superior de Investigaciones Científicas (Spanish Higher Council for Scientific Research) or CSIC, and the research institutes and hospitals of the Public Health System. All of these institutions are located in the Andalusian region of Spain. The dependent variable is the number of patents applied for by these public institutions from 2002 to 2005. The justification for this sampling period is twofold. First, the availability of data for the explanatory variables (as explained later, the information for the explanatory factors is not available for any previous period) determines the starting year. Second, after 2005 university patent data substantially decreased because some new applications were still in the revision process or simply had not yet been included in the database.

The procedure to collect the patents developed and applied for by each group was as follows. From a comprehensive search in the databases of the Spanish Patent and Trademark Office, we identified 252 patents that included at least one researcher belonging to one of the research groups in the Andalusian public research system as an applicant (researchers with no relation with any research group applied for 22 patents). We then assigned these patent applications to one of the 1,120 research groups according to the name of the inventor and the institution at which the research was conducted. The Junta de Andalucía (regional government) provided the list of research groups, including the names of the inventors.

Finally, we classified the data by the area of knowledge in which the group worked: 1) Agriculture; 2) Science and Health Technologies; 3) Life Sciences; 4) Physics, Chemistry, and Mathematics; 5) Natural and Marine Resources; 6) Production Technologies; and 7) Information and Communication Technologies[1]. Table 2 provides a breakdown of the research groups by subject area and their composition. Note that for this particular Spanish region, innovation in public institutions plays an important role in the entire regional innovation system. In evidence, during the sample period considered, 356 patents in total were applied for in Andalusia (including all private companies, universities, and research institutes), with patents applied for by universities and public research centres accounting for 70.8%.

Table 3 details the characteristics of the patents. As shown, patents are over-concentrated in two of the major technology sector groupings, with the greatest shares of applied patents concerned with "Chemicals and Pharmaceuticals" and "Instruments". There are also significant differences across groups in the two largest public research institutions (universities and the CSIC). Whereas universities obtain patents in both of these technology areas, the patents for the CSIC mainly fall under "Chemicals and Pharmaceuticals", especially the subgroup "chemicals for agriculture and food

[1] Two other areas of knowledge, 8) Social and juridical sciences and 9) Humanities, were deliberately excluded as they are not involvement with the generation of patents.

industries". We consider that this difference is because the CSIC centres are established territorially with stronger links to the productive structure of the region than universities, which tend to be more spread around the region and typically encompass activities that are more diverse.

TABLE 2 ABOUT HERE

TABLE 3 ABOUT HERE

Other data in the analysis includes the explanatory variables capturing the characteristics of the research groups. To avoid problems with endogeneity, the explanatory variables correspond to the data for the whole period 1999–2002 (while the dependent variable is for 2002–05). The temporal reference (1999–2002) is the same for all of the explanatory variables. Besides preventing endogeneity, the underlying reasons for this particular temporal interval include the availability and reliability of the data. The scientific background and links with the private sector of the various groups are from a database maintained by the Andalusian regional government (Consejería de Innovación, Ciencia y Empresa). Although containing information for previous years, the data are only reliable for the above sample period. Furthermore, it was not possible to obtain yearly data. A detailed description of the explanatory variables is as follows:

Intjn: The number of articles published in international journals during the period 1999–2002 captures the scientific background of the group. This variable provides a measure of both the quantity and the scientific quality of the research carried out by the group.

Cont: This is the number of scientific–technical contracts with private or public companies signed by the group in the period 1999–2002. This variable captures the collaboration of the group with the business world and with the actual needs of companies. It also relates to the external financing of the group, as researchers receive fees or other financial compensation in return for consultancy, assistance, or collaboration provided under such contracts.

In this paper, we specifically focus on these two variables. However, according to the literature review, a number of other factors affect the production of patents. Therefore, it is necessary to control for these other explanatory factors, including the human and financial resources in the group and the affiliation of the group with a specific type of institution:

Posdocs: We take the size of the research group into account with the potential number of people involved in the production of technology. The number of researchers with a PhD in the research group is the variable that best captures this fact (other members of the group, such as administrative personal, were excluded).

Proj: To include the capacity of the group in obtaining financial resources from the government, we use the number of research projects with public financing awarded to the group during the period 1999–2002. A more suitable measure would have been the financial resources for each project; unfortunately, this information is not available.

We capture the institutional affiliation of the research group with different incentive policies in promoting patent production using two dummy variables:

Univ: This variable takes a value of 1 if the research group is affiliated to a university and 0 otherwise.
Csic: This variable takes a value of 1 if the research group is affiliated to the CSIC and 0 otherwise.

The base (or reference) category captures groups working in the regional healthcare system. The literature review generally explains why affiliation is important. In our particular case, these variables are relevant for two reasons. First, dedication to scientific and technological activities is not constant in each institution. For instance, researchers in the CSIC devote themselves exclusively to research work, while academic staff in universities divide their time between teaching and research. Professionals in hospitals also divide their time, but between the clinical care of patients and research. Second, not all institutions have the same policy with respect to the generation of technological knowledge. For example, the CSIC traditionally maintained a policy of actively protecting the results of its research, whereas universities never specifically promoted the protection of their research results, though this is now implicitly encouraged.

Finally, we control the differences in the propensity to patent by including a group of dummy variables capturing the area of knowledge in which each group is assigned. *Agr* (Agriculture), *Sth* (Science and Health Technologies), *Ls* (Life Science), *Pcm* (Physics, Chemistry and Mathematics), *Nmr* (Natural and Marine Resources), and *Pt* (Production Technologies); the reference category is *Ict* (Information and Communications Technologies). Table 4 summarizes the list of variables, their statistical source, and the relationship of each variable with the hypotheses.

TABLE 4 ABOUT HERE

Table 5 provides the distribution of university patent counts for the 1,120 research groups affiliated to each public institution. As shown, 84.5% of the observations are zero, indicating that in at least eight out of ten cases, research groups applied for no patents in that period. Tables 6 and 7 include descriptive statistics and the correlations between the variables. Note that the variable "scientific background" of the group, captured by the number of papers in high quality journals (Intjn), and the "qualified human resources" of the group, captured by the number of members with a PhD (posdocs), display the highest correlation among the explanatory variables.

TABLE 5 ABOUT HERE
TABLE 6 ABOUT HERE
TABLE 7 ABOUT HERE

4. Model

The standard model for the generation of technological knowledge is a knowledge production function (Griliches, 1979). This approach usually specifies patent count as the dependent variable, obtaining a production function of patents of the form (Hausman et al., 1984; Blundell et al., 1999; Foltz et al., 2003; Gurmu et al., 2010):

$$Y_{it} = f(X_{it}, u_{it}) \quad i = 1,\ldots N;\ t = \text{period of time}$$

where Y is the number of patents produced by universities, laboratories, research groups, etc., X is a set of explanatory variables, and u is the usual random term. Following this standard framework, we estimate a patent production function. The conditional mean is specified as:

$$E(Pat_{it} / X_{it-v}, z_{it-v}, u_i) = \exp(X_{it-v}\beta + z_{it-v}\gamma)u_i,$$

where *Pat* is the count of patents issued to each research group affiliated to a public institution, X = (*Cont*, *Intjn*) is the vector of explanatory variables upon which we focus on, and z captures other characteristics of the group where z = (*Proj*, *Posdocs*, *Univ*, *Csic*, *Agr*, *Sth*, *Ls*, *Pcm*, *Nmr*, *Pt*). Finally, u captures any unobserved group heterogeneity.

As is well known, it is customary to establish a temporal relationship between the dependent variable and the explanatory variables. In our sample, we do not have yearly data, with our patent information drawn from 2002–05 and the explanatory variables from 1999–2002. Therefore, the lags may lie anywhere between one and six years, a reasonable lag according to the literature (see Gurmu et al., 2010).

Two specific attributes associated with the dependent variable are important for specifying the empirical model: it is discrete and exhibits a large number of zero observations. A Poisson specification is often the starting point for modelling a count variable; however, the application of the Poisson model requires the equality of means and variances, a requirement we cannot always meet in practice. Importantly, if the data display overdispersion, the standard errors of the Poisson model will be biased to the lower end, resulting in spuriously high values of the t-statistic (Cameron and Trivedi, 1986). The most common formulation for taking into account the overdispersion of data is the negative binomial model (NB), as it assumes that the variance is a quadratic function of the mean (see Cameron and Trivedi, 1998 for a comprehensive discussion of the estimation procedure). To consider the abundance of zero observations in the sample, we introduce zero-inflated, nonlinear count data, zero-inflated Poisson (ZIP) (Lambert, 1992), and zero-inflated negative binomial (ZINB) (Heilbron, 1994) models. These models have been widely used in other empirical studies with similar objectives to the current research (for example, Azagra-Caro et al., 2006; Foltz et al., 2003; Stephan et al., 2007). The zero-inflated distribution can be interpreted as a finite mixture with a degenerate distribution whose mass is concentrated at zero. This model contains two sources of overdispersion: one that permits a number of extra zeros, and another that introduces the individual heterogeneity of the set with positive values. The proposal of the density function, the logarithmic likelihood function, and the first-order conditions, etc., are comprehensively discussed in Cameron and Trivedi (1998).

5. Results

Table 8 summarizes the results for the estimated models (Poisson, NB, ZIP, and ZINB). The diagnostic tests are in Table 9, where we have calculated the usual statistics that measure the goodness-of-fit model and the "fitted frequency probabilities". The diagnosis tests indicate the significance of the overdispersion parameter, which determines the suitability of the negative binomial models over the Poisson models. The Vuong (1989) statistic shows that ZIP and ZINB are preferred over the simple Poisson and NB models, while ZINB performs better than ZIP.

The coefficient of the variable *Cont* (number of contracts with private or public companies) –capturing the effect of collaboration– is significant and positive in all models. That is, research groups linked to companies through contracts to attend to their technological demands, tend to produce more patents.

The coefficient of the variable *Intjn* (number of articles published in international journals) –showing the effect of scientific background of the group– is also significant and positive in all models. According to this result, the scientific background of the research group positively relates to the generation of patented technology in subsequent periods.

The estimated results indicating the effects of the other variables included in the analysis show that the coefficient of *posdocs* is positive but not significant. Therefore, the size of the group in terms of the number of postdoctoral researchers is not significantly related to the production of patents at this scale of analysis. Possibly this is because, as pointed out by Hemlin et al. (2008), creativity in groups is more related to the task and the stage of work than their size or structure. The variable *Proj* is not relevant in any model. This is not surprising given the number of awarded public projects aimed mainly at attaining research objectives rather than for obtaining patentable technological knowledge. In addition, this variable does not include the amount of money the group receives, unavailable for the purpose of this analysis.

The dummy variables capturing the public affiliation (*Univ, Csic*) are both positive and significant. This shows that both the way in which research is organized and the different patent policies and incentives in each type of institution affect the production of patents. On average, CSIC and universities produce more patents than Public Health Institutions. The CSIC displays a coefficient with a magnitude greater than that for universities, a result entirely consistent with the objective of this public institution (producing scientific and technological outputs). Finally, the two dummy variables capturing the different propensities to patent across the several fields of research show that groups in the areas of *Sth* (Science and Health Technologies) and *Nmr* (Natural and Marine Resources) produce fewer patents than groups in other fields.

Further analyses to check the sensitivity of our results were carried out. First we estimate the previous models by including all explanatory variables except *postdocs*. Second, we excluded *Intjn* keeping *postdocs*. The reasoning is that the variable *posdocs* (number of PhD members in the group) and *Intjn* (number of papers in international journals) are correlated (the higher the number of PhDs in the group, the larger the number of scientific publications). Although the correlation coefficient between these variables is not high (0.4356), the insignificant coefficient for *postdocs* is perhaps an indicator of multicollinearity. The revised results show that *posdocs* is actually an irrelevant variable in explaining the production of patents by research groups, with the estimated coefficient remaining insignificant or become significant only at the ten percent level when *Intjn* is excluded from the model. The estimates of the remaining coefficients are unchanged[2].

TABLE 8 ABOUT HERE

TABLE 9 ABOUT HERE

6. Discussion and implications

The estimated models presented above favor both hypotheses put forward in this paper. Our results show that the external collaboration of research groups matters. This finding is consistent with previous literature carried out at other levels of analysis. For example, Acosta et al. (2005), Miyata (2000), Owen-Smith and Powell (2003) found a positive and significant effect of collaboration on university innovation (or patents). Moreover, the scientific background of the research group positively relates to the generation of patented technology in subsequent periods. Similar results at the individual level were found by Azoulay et al. (2007), who concluded that patenting events are preceded by a sequence of publications. Stephan et al. (2007) also stressed this relationship. Note that, as in Ahmadpoor and Jones (2017), the prevalence of patents linking back to scientific background is consistent with institutional views of the linear model. However, this outcome does not mean that our results are incompatible with other interactive models of innovation, but simply that our data do not address potentially "non-linear" reverse linkages where technological advances may also drive scientific progress.

Our findings also suggest that the production of patents varies widely among the various types of public institutions according to their different objectives and policies. Previous research obtained similar conclusions, with several studies stressing that the kind of organization and the policies used to promote innovation and technology transfer in organizations matter (Azagra-Caro et al., 2006; Coupé, 2003; Henderson et al., 1998). Together, these studies provided important insights into the relationship between patent activity and institutional factors or policy measures.

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[2] For the sake of clarity, we do not present these new models, but they are available upon request.

One of the main implications of our results is that there are two types of synergies. The first stems from working with private companies. This collaboration increases their capacity to produce patented technologies, and firms benefit from university knowledge. This type of synergy might also contribute to strengthening the innovation system. It can also play a relevant role in the knowledge management of smart city projects, where firms and universities might contribute with their knowledge to the development of smart cities. This means that universities would have a crucial function in reducing the knowledge distance between different project partners. The recent paper by Ardito et al. (2018) includes a full discussion on this topic. The second derives from the scientific background, since groups with better scientific capacity are more efficient in the production of technological outputs.

Referring to the first type of synergy, the main message of this paper is that collaboration with firms should be seen as an asset, and some incentives to research groups might be focused on avoiding barriers that prevent them from collaboration with private companies, perhaps by establishing a better funding system for those groups involved in collaboration. However, increasing motivation through incentives is just part of the policy. Suggesting policy measures favouring collaboration is not an easy task because any proposal should be tailor made, which means putting forward a diagnostic of the two parties involved in the collaboration process –firms and research groups– along with the potential obstacles to bring together both institutions. First, it is relevant to identify not only the potential of the scientific group in terms of physical and human resources, but also its level of specialization, capacities and advantages in particular fields, motivation for collaboration, and university practices of academic patenting. Second, it would be necessary to examine the potential demand for technology of surrounding firms, and the gaps that the scientific group could fill. Third, it is important to find out the mechanisms that may limit the depth and quality of interactions between research groups and businesses (see for example Bruneel et al., 2010, and Villani et al., 2017 for a review of the barriers associated with university-industry collaboration, and Weckowska et al, 2018, for the role of local practices to encourage academic patenting). Undoubtedly, the best way to put into practice a whole policy of collaboration between scientific groups and industry is under the umbrella of the university as suggested by Ankrah and Omar

(2015), but taking into account the special characteristics and specialization of the research group, which is ultimately the provider of the technological knowledge.

Regarding the second synergy, the risk of research groups being diverted from one of their main tasks (conducting research) does not seem to be significant, as the groups with stronger scientific backgrounds were found to be those more capable of producing technological outputs with industrial applications. This result links with the debate on the negative impact of collaboration with private companies, which main argument is that patenting could divert the public research agenda towards commercial objectives, or may produce a crowding-out effect (diverting human or public economic resources to objectives other than research). This suggestion is difficult to support based on our results because the research groups found to be collaborating with companies and obtaining scientific research outputs produce more patents. Therefore, patents usually arise as an additional and subsequent output supported by both the flow of tacit knowledge between research groups and companies, and the scientific knowledge produced by the group. Moreover, we find no crowding-out effect because the production of patents is not determined by the number of public projects granted to the groups.

7. Conclusions

This paper contributes to the literature on knowledge production by analysing the generation of patents at the research group level. This is relevant for two reasons. First, previous papers have dealt with the production of knowledge at the university and laboratory levels. To our knowledge, this is the first attempt to explore some of the factors affecting the production of patented technology in public research institutions at the research group level. Second, the research groups and universities play an important role in the regional and national innovation systems, as well as in smart city projects; therefore, providing some insights into the reasons why some research groups are more efficient than others might offer some clues to policy makers in order to increase university technological outputs.

We particularly focused on the effects of collaboration and the scientific background of the group. Using a sample of 1,120 publicly affiliated Spanish research groups from seven areas of research, we employed a standard empirical procedure consisting of the estimation of Poisson and NB models and other regressions that take into account the excess of zero observations in our sample (ZIP and ZINB). Diagnostic tests and the forecasting analysis of counts indicated the ZINB model was preferred.

The findings of this preferred model favour the hypotheses put forward in this analysis: namely, that collaboration with private companies and the scientific background of the research group positively and significantly relate to the production of patents. Both findings are also consistent with the previous literature using other scales of analysis. The coefficients of the other variables in the analysis also suggested that there are significant differences between the type of public institution to which the group is affiliated and its field of research, though we did not find any significant effects associated with the size of the group or the number of public projects.

The main limitations of our analysis stem from the fact that data on the amount of economic resources received by the groups were not available. We partially resolved this problem by including the number of research projects as a proxy for public grants, but the estimated coefficient obtained was not significant in any model. We suggest that this is because, while most of the research groups in our sample rely on projects for financing their scientific expenditure, the objectives of most public grants concern research and obtaining research output, not the production of technological outputs. In addition, the insufficient number of observations prevented us from estimating the models by field of research or type of public institution, although several dummies were included in the main analysis to capture these effects.

For future research on this topic, we suggest the inclusion of additional evidence at this scale of analysis using samples in other contexts that overcome the limitations of this paper. As a second extension, our hypotheses draw heavily on the patent production literature. We think that linking this strand of literature with the creativity literature in research groups could lead to additional fruitful outcomes. This is because taking a "group" perspective is a promising field of research, as the scientific and technological creativity literature stressed (Amabile, 1996; Ekvall, 1997; Ford, 1996; Hemlin, 2009;

Hemlin et al., 2004, 2008; Henze et al., 2007; Woodman et al., 1993). This could potentially provide a broader theoretical framework to identify other characteristics of the group that may encourage or hinder the technological creativity leading to a greater production of patents. Creativity in research and innovation is a broad concept traditionally studied by various disciplines. According to this perspective, the environment in which the individual works is important for enhancing creativity and productivity. For example, Hemlin et al., (2004) established a component list of factors where knowledge environments depend on task characteristics, the kind of discipline/field, the characteristics of individuals and research groups, the general work situation for individuals, physical environment, organization, and the extra-organizational environment. These factors were classified in three categories (Hemlin et al., 2008): macro (including the global, national, and interorganizational levels), meso (research institutions, business companies, and regions), and micro (research groups, work teams, and individuals). At each level, one can identify environmental factors that support or hinder creativity and innovation. Surveys and a multilevel econometric framework (Skrondal and Rabe-Hesketh, 2008; Wooldridge, 2003) considering several hierarchical structures of factors (at the individual, group, university, and even industrial environment level) involving the production of patents would be a suitable methodology for consistently testing these hypotheses. Another promising line of research would be the new tasks of universities in a given knowledge-based ecosystem, as represented by the smart city projects (Ardito et al., 2008). In particular, the role of research groups as knowledge providers and their contribution to the development of smart cities.

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Table 1 Selection of studies on the production of patents at the university and laboratory level

Author	**Location**	**Unit of analysis**	**Obs./ Period**
Henderson et al. (1998)	US	University level	1965-1988
Coupé (2003)	US	University level	537 US Universities 1969-1994
Foltz et al. (2003)	US	University level	128 US Universities 1994-1999
Payne and Siow (2003)	US	University level	45 US Universities 1996
Miyata (2000)	US	University level	69 US Universities 1996
Owen-Smith and Powell (2003)	US	University level	89 US Universities 1988 - 1998
Geuna and Nesta (2006)	EU	University level	Paper review
Saragossi and Van Pottelsberghe (2003)	Belgium	University level	6 Belgian Universities 1985-1998
Acosta et al. (2005)	Spain	University level	47 Spanish Universities 1998-2010
Baldini et al. (2006)	Italy	University level	63 Italian Universities 1965-2002
Glauber et al. (2015)	Germany	University level	328 German higher education Institutions 2002-2011
Fisch et al. (2015)	Worldwide	University level	Top 300 universities in ARWU 2013
Coronado et al. (2017)	Europe	University level	360 European Universities 2001-2004
Azagra-Caro et al. (2003)	Spain	Department / laboratory level	43 Departments 1991-2000
Azagra-Caro et al. (2006)	France	Department / laboratory level	83 Academic laboratories 1993-2000
Arvanitis et al. (2008)	Switzerland	Department / laboratory level	202 Science institutes 2002-2004
Gurmu et al. (2010)	US	Department / laboratory level	159 Laboratories 1985 -1999

Table 2 Breakdown of the research groups

Subject Area	Nº of Groups	Nº of Researchers with Doctorates
Agriculture	114	705
Sciences and Technologies of Health	300	1,960
Life Sciences	155	809
Physics, Chemistry, Mathematics	214	1,361
Natural and Marine Resources	168	944
Production Technologies	91	485
Information and Communications Technology	78	562
TOTAL	1,120	6,826

Source: Consejería de Innovación, Ciencia y Empresa (Junta de Andalucía) and Authors' own elaboration

Table 3 Patents by technology sector and institution 2002/2005

Technology Sector	Univ	CSIC	Others	Total
I. ELECTRICAL ENGINEERING				
1. Electrical machinery & equipment, electrical energy	4	1	0	5
2. Audiovisual technology	2	1	0	3
3. Telecommunications	8	0	0	8
4. Information Technology	4	0	1	6
5. Semiconductors	0	1	0	1
II. INSTRUMENTS				
6. Optical	1	0	0	1
7. Analysis, Measurement and Control Technology	38	1	2	41
8. Medical Technology	16	0	0	16
III. CHEMICALS & PHARMACEUTICALS				
9. Fine organic chemicals	15	2	3	20
10. Macromolecular chemicals, polymers	4	0	0	4
11. Pharmaceutical and cosmetic products	10	3	1	14
12. Biotechnology	28	6	3	37
13. Materials, metallurgy	7	3	0	10
14. Agriculture, food chemicals	7	5	0	12
15. Industrial & petrochemicals; Basic mat'ls chemistry	6	5	1	12
IV. PROCESS ENGINEERING, SPECIAL EQUIPT.				
16. Chemical engineering	20	1	0	21
17. Surfaces & coatings technology	3	1	0	4
18. Materials, textiles, paper processing.	2	0	0	2
19. Thermal processes and equipment	0	0	0	0
20. Environmental technology	7	0	1	8
V. MECHANICAL ENGINEERING, MACHINERY				
21. Machine tools	0	0	2	2
22. Motors, pumps and turbines	0	0	0	0
23. Mechanical Items	0	0	0	0
24. Mechanical Handling, Printing	2	0	0	2
25. Mach. & equipment for agriculture & food treatment	4	1	0	5
26. Transport	1	0	0	1
27. Nuclear power engineering	0	0	0	0
28. Space and defence technology	1	0	0	1
29. Capital and consumer goods	9	0	1	10
30. Civil engineering, construction and mining	7	0	0	7
TOTAL	206	31	15	252

Source: Spanish Office of Patents and Trade Marks, and Authors' own elaboration

Table 4 Definition of explanatory variables

Exp. Variab.	Name	Hyp.	Description	Source
Contracts	Cont	H1	Number of scientific-technical contracts with private or public companies signed by the members of the group	PAI[a]
International journals	Intjn	H2	Number of articles in international journals published by the members of the group	PAI[a]
Numb. Researchers PhD	Posdocs		Number of researchers with a Doctorate degree belonging to the group	PAI[a]
Projects	Proj		Number of research projects with external public financing undertaken by the members of the group	PAI[a]
University	Univ		Group affiliated to a public university of Andalusia	IGI[b]
CSIC	Csic		Group affiliated to the CSIC	IGI[b]
Agriculture	Agr		Scientific area of Agriculture	IGI[b]
Sci. and technol. Health	Sth		Scientific area of Sciences and Technologies of Health	IGI[b]
Life Sciences	Ls		Scientific area of Life Sciences	IGI[b]
Physics, Chem. Math.	Pcm		Scientific area of Physics, Chemistry and Mathematics	IGI[b]
Nat,.Marine Resources	Nmr		Scientific area of Natural and Marine Resources	IGI[b]
Prod. Technologies	Pt		Scientific area of Production Technologies	IGI[b]

[a] PAI: Andalusian Plan for Research

[b] IGI: Inventory of Research Groups

Table 5 Observed frequency of dependent variable

Patents Count	Observed Freq	%
0	947	84.55
1	104	9.29
2	40	3.57
3	20	1.79
4	4	0.36
5	5	0.45
0bs	1,120	100

Table 6 Descriptive statistics.

Variable	Obs	Mean	Std. Dev	Min	Max
Pat	1120	0.2545	0.7077	0	5
Intjn	1120	22.633	20.932	0	193
Cont	1120	1.9777	4.5193	0	55
Posdocs	1120	6.0955	3.3785	1	24
Proj	1120	1.0741	1.7279	0	24
Univ	1120	0.8161	0.3876	0	1
Csic	1120	0.0928	0.2904	0	1
Agr	1120	0.1018	0.3025	0	1
Sth	1120	0.2678	0.4430	0	1
Ls	1120	0.1384	0.3455	0	1
Pcm	1120	0.1911	0.3933	0	1
Nmr	1120	0.1500	0.3572	0	1
Pt	1120	0.081	0.2733	0	1

Table 7 Correlation matrix

	Pat	Lintjn	Lproj	Lcont	Lposdoc	Csic	Univ	Agr	Sth	Ls	Pcm	Nmr	Pt
Pat	1												
Lintjn	0.099	1											
Lproj	0.0401	0.2493	1										
Lcont	0.1835	0.1901	0.2377	1									
Lposdoc	0.0809	0.4356	0.178	0.1666	1								
Csic	0.0502	0.0676	-0.0397	-0.0105	-0.0636	1							
Univ	0.0437	0.0776	0.1249	0.1567	0.051	-0.6739	1						
Agr	0.025	0.0394	0.1002	0.1987	0.0232	0.1772	-0.0765	1					
Sth	-0.1292	-0.101	-0.1688	-0.2333	0.073	-0.1727	-0.2176	-0.2036	1				
Ls	0.0532	0.0254	-0.0268	-0.1097	-0.0826	0.1212	-0.03	-0.1349	-0.2424	1			
Pcm	0.0274	0.1427	0.0217	-0.1456	0.0474	-0.1085	0.1956	-0.1636	-0.294	-0.1948	1		
Nmr	-0.0769	0.0405	0.0704	0.2069	-0.0431	0.1068	0.0187	-0.1414	-0.2541	-0.1684	-0.2042	1	
Pt	0.1517	-0.1416	-0.0144	0.1685	-0.0794	-0.0501	0.1074	-0.1001	-0.1799	-0.1192	-0.1445	-0.1249	1

Table 8 Count models explaining the production of patents by research groups

	POISSON (1)			NB (2)				ZIP (3)			ZINB (4)		
	Coeff	Std. Err.		Coeff	Std. Err.			Coeff	Std. Err.		Coeff	Std. Err.	
Constant	-4.5096	1.0615		-4.4085	1.1204		Constant	-4.800	1.0416		-4.9232	1.0570	
Lintjn	0.197	0.0718	**	0.2271	0.0983	**	Lintjn	0.1701	0.0826	**	0.1969	0.0910	**
Lproj	-0.040	0.0416		-0.0309	0.0583		Lproj	-0.037	0.0473		-0.0350	0.0552	
Lcont	0.2206	0.0366	**	0.2144	0.0493	**	Lcont	0.1426	0.04065	**	0.1863	0.0483	**
Lposdocs	0.1802	0.1364		0.8870	0.1903		Lposdocs	0.0117	0.1660		0.090	0.1851	
Csic	2.8981	1.0284	**	2.9206	1.0665	**	Csic	4.1302	1.0346	**	3.6844	1.0480	**
Univ	2.4643	1.0134	**	2.4849	1.0359	**	Univ	4.2614	1.0109	**	3.6679	1.0220	**
Agr	-0.2701	0.2661		-0.3466	0.3750		**Inflate**						
Sth	-0.6082	0.2764	**	-0.5898	0.3637		Csic	11.1435	804.9665		10.1936	788.9798	
Ls	0.2919	0.2484		0.2379	0.3488		Univ	12.0181	804.9663		11.2536	788.9794	
Pcm	0.0794	0.2443		-0.0591	0.3401		Agr	0.4970	0.4635		0.8700	0.7556	
Nmr	-1.0930	0.2995	**	-1.1188	0.3863	**	Sth	1.1258	0.4426	**	1.5130	0.7053	**
Pt	0.6329	0.24674	**	0.6753	0.365	*	Ls	0.0098	0.4434		-0.0928	0.7939	
							Pcm	0.2651	0.4170		0.4031	0.7025	
							Nmr	1.4606	0.4691	**	1.9685	0.7392	**
							Pt	-1.0058	0.5119	**	-13.039	935.429	
							Constant	-11.467	804.9664		-11.7892		
N. Obs.		1,120			1,120				1,120			1,120	

**Significant to 5%
* Significant to 10%

Table 9 Diagnosis test

	POISSON		NB		ZIP		ZINB	
Voung test					5.23	**	3.55	**
Likelihood-ratio			113.03	**			10.72	**
Log Likelihood	-681.77		-625.25		-624.54		-619.18	
LR chi2	186.98	**	98.53	**	24.79	**	30.58	**
Fitted frequency probabilities								
Pr0	0.7922		0.8428		0.8440		0.8451	
Pr1	0.1697		0.1055		0.0947		0.0989	
Pr2	0.0312		0.0302		0.0421		0.3421	
Pr3	0.0056		0.0112		0.0140		0.0128	
Pr4	0.0010		0.0048		0.0039		0.0051	
Pr5	0.0002		0.0023		0.0009		0.0021	
N. Obs.	1,120		1,120		1,120		1,120	