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Measuring university–industry collaboration in a regional innovation system

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Abstract Studies of university–industry collaboration remain subject to important limitations due to the shortage of empirical data and a lack of consistency in that obtained to date. This article puts into practice a set of universities Third Mission indicators in a regional innovation system. Selected indicators previously compiled from literature were reorganized and pre-tested. We have undertaken two face-to-face surveys of 737 firms and 765 heads of research teams, respectively. The results test the validation of indicators and provide a complex map of university–industry linkages as well as some observations on the flexibility needed to address this issue.

Keywords Indicators · University–industry collaboration · Regional innovation system

Introduction

Third Mission activities in universities related to the generation and application of knowledge outside the academic environments are currently a topic of growing importance in the agendas of both R&D policymakers and university administrators (Martin et al. 1996; Etzkowitz et al. 2000; Mowery et al. 2001). Universities are often described as "engines for growth" which generate skills and research results that are significant sources of innovation for firms, especially in some industrial fields (Mansfield 1995; Pavitt 2001). The need firms have for new knowledge (Meyer-Krahmer and Schmock 1998; Schartinger et al. 2002) and universities have for financing (OECDE Secretarit 1999; Santoro and Gopalakrishnan 2000) generates an interdependence between them (Geisler 1995) that constitutes a driving force behind their collaboration. Furthermore, such transformation appears to be linked to the increasingly diversified roles of universities (Godin and Gingras 2000) and the growing legitimacy that relationships with industry are acquiring in academia (Colyvas and Powell 2006).

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Numerous governments and research agencies are seeking ways to facilitate the interactions between industry and universities with the hope that they can improve productive processes and competitiveness in their national or regional environments (OECD 1998, 2007). Growth of these activities has created a demand for suitable information for decision making on several managerial levels. In the public policy sphere a precise diagnosis of university relationships with their socioeconomic settings is needed in addition to useful tools for evaluating the programs aimed at fostering cooperation. On the university side, the professors' Third Mission activities must be identified in order to quantify their weight in comparison with traditional academic teaching and research tasks. However, a consensus has yet to be reached regarding the optimal indicators for evaluating activities carried out by academics and firms in collaborative endeavors.

Recent contributions to the specialized literature insist on the complexity of university–industry interconnections. It is widely acknowledged that this interaction does not follow one single pattern (Thune 2007). In fact, there is a growing awareness of just how little is understood regarding the ties that bring them together (D'Este and Patel 2007) and the lack of in-depth studies on the effects of current policy (Woolgar 2007). As a result, an increasing number of scholars are pointing to the need for further research on the suitability of the existing sources for measuring Third Mission performance as well as for the development of new potential indicators. Relevant reports on this subject matter typically establish two types of recommendations (Howells et al. 1998; Polt et al. 2001; Molas-Gallart et al. 2002): first, to include an ample set of items which go beyond outputs related to the commercialization of results and intellectual property protection; and second, to set up data collection systems that are able to portray the diversity of activities inherent to the organizations involved in producing them.

Our study incorporates those suggestions into a set of indicators that traces the current trends which the main actors in a regional innovation system are actually following. Based on the assumption that knowledge exchange takes place through multiple channels and that practices which attempt to exploit codified scientific knowledge, such as patents or spin-offs, are only a small part of the process, our aim is to contrast that reality with the information provided by an in-depth analysis in which we observe the collaborative linkages between universities and firms from the point of view of both partners. The goals of the paper are two-fold: first, we develop a specific set of indicators that comprises the plurality of interactions that take place *in the real world*. Our main contention, in an attempt to unravel this complexity, is that the study of the phenomenon of interaction between academia and industry should cover the widest range of channels and mechanisms. Second, we provide substantive evidence of the existing situation in a regional innovation system. In this way we test the consistency of the indicator set and we capture the structure of relationships between them as well.

The study was conducted in Andalusia, a region in southern Spain with a large public university system and an industrial sector made up mainly of traditional small and medium enterprises (SMEs) with a lack of innovation capabilities (CES 2008). Nevertheless, modernization policies and the emergence of new companies in the last few years, along with the diversification of higher education institutions, are resulting in more heterogeneous relationships between firms and universities in the region. Andalusia is generally considered a catch-up region in the context of the European Union with respect to the generation of scientific knowledge and the innovation capacity of the productive sector (OECD 1996, 2008). The empirical basis for our analysis resides in two surveys of 737 firms and 765 heads of research teams conducted in 2008. Our sample of firms reflects the diversity of sectors, sizes and innovative profiles for industry in our region of study. In a similar way, our sample of research teams reflects the diversity of fields, ages, sizes, and types of centers. The surveys include a comprehensive set of variables covering different types of relationships of universities and public research organizations[1] with industry. This study, therefore, contributes to the existing discussion on the metrics of university–industry links by generating an original data source, and by applying a comprehensive indicator set which can fill the gaps currently present in the data from official statistics and institutional reports. We also compare participation in collaborative activities by firms as well as research teams. This constitutes an approach not usually taken in this kind of analysis. Putting the two surveys together can add validity to the designed set of indicators. Collectively this enables us to build what constitutes a complex map of interactions between universities and firms in a regional domain and reflect upon the inadequacy of the indicators normally used to measure Third Mission activities.

To begin with, the paper analyzes the main related debates in the current literature, with special emphasis on the methodological caveats. From there, the variety of interactions between universities and firms is evaluated and contrasted with our empirical results. To that end we proceed to describe our data sources, the main procedures of the field work conducted, the characteristics of our samples and the set of indicators employed. Next, descriptive results are presented, followed by factor analyses aimed at detecting the structure of relationships between actors. In a final section we draw some conclusions from the case study regarding the specific characteristics of knowledge transfer and cooperative linkage for further discussion. Our study confirms the need to provide flexibility to the system of indicators to improve their degree of adaptation to the existing complexity, as well as the need to combine them with additional evaluation schemes.

The conditioning factors for the study of collaborative instances between universities and firms

The analyses which empirically address the university–industry collaboration are generally done from the viewpoint of only one of the two actors that participate in the relationship. Studies of innovation, conducted principally by economists, turn to the characteristics and activity of the firms as their reference, while studies which focus on higher education use universities to make their observations. Both kinds of studies apply specific methodological tools, and each have their advantages and disadvantages.

Firms

Business innovation surveys use indicators where the entity being analyzed is the firm. Empirical research in this field runs into different types of problems when making comprehensive observations about university–industry relationships.

- Projects specifically designed to examine this issue tend to focus on industrial sectors that are closely linked to research, such as biotechnology (Hicks et al. 2001; Owen-Smith

[1] Our study also includes non-university public research organizations, mainly the Spanish National Research Council centers and the regional government laboratories in the agricultural and health sectors. The joint size of these centers is considerably limited relative to the activity of universities in the region. However, almost all of these organizations have a legal status and labor conditions similar to the universities. In order to simplify we will only refer to universities in the text although it should be noted that by this we also mean public research organizations.

and Powell 2004). Numerous studies are based on firms with particular characteristics, normally those with R&D departments (Cohen et al. 2002), start-ups related to high-tech production processes and, in some cases, spin-offs that emerge from a small number of universities with high research levels (Shane 2002). Therefore they are found to be notably biased when they are examined outside the knowledge-intensive environments where these enterprises usually operate. Consequently, their results are difficult to extrapolate to the small and medium-sized innovative firms that are commonplace in much of the developed world, and especially in most of the catch-up regions.

• Studies that examine wider samples normally utilize data sources that are not designed for the purpose of university–industry collaboration such as the Community Innovation Survey—CIS—(Stockdale 2002; PITEC 2007). Although these empirical analyses cover a full range of enterprises, their measurement tools do not permit detailed information to be gathered on the many types of interactions, nor do they account for the strategies and expectations of the firms involved. Given that the aim of these surveys is not to apprehend this particular business behavior, summary measures employed do not provide insights into the complexity of the relations. Instead, the analyses are mainly based on "proxy" variables that reflect, in a very general way, the variety of links and their intensity (Mohnen and Hoareau 2003). Thus, although these studies lead to relevant conclusions, they are highly abstract and difficult to translate into practical implications given the diverse situations in which university–industry interconnections occur.

• Furthermore, the heterogeneity of sources leads to remarkable differences in the existing empirical studies. While the results obtained in Europe tend to be consistent across countries (OECD 2002), they contrast notably with analyses conducted in North America, making international comparisons extremely difficult (Owen-Smith et al. 2002). This variation in the outcomes could be a consequence of the multiple methods used. When firms are given a specific questionnaire centered on their interactions with universities, the results of the survey are different from those innovation studies which take into account collaboration issues in a more generic sense (Laursen and Salter 2004).

Analyses to date have also shown that numerous factors shape the relationship. One set of influences comes from factors which could be called "structural", such as the size of the company, the productive sector, or how long it has been in business. Normally the strongest links take place in large companies, and in those that do work in technology intensive sectors (Arundel and Geuna 2004). A second group of factors points to the importance of the strategic search processes pursued by the firm. The most dynamic ones use management procedures that encourage an open system of innovation (Chiesa and Manzini 1998). The third type can be called "situational factors", which are related to the makeup of the social or economic environment where the firm is located. Relationships between universities and firms are linked to personal interactions between individuals. They are born from common and overlapping interests from both sectors and often take place through exchanges which are negotiated informally (Mowery et al. 2001). The scope of influences leads firms to diversify their collaboration channels with universities as a function of their absorptive capacity, their innovation strategies and the possibilities of setting up cooperative networks. Elsewhere, we have shown empirically how all these factors affect different kinds of relationships (Fernández-Esquinas et al. 2009). When indicators are used that take into account the diverse situations in a business milieu, a range of types of interaction with universities emerge which are not normally visible to policy makers.

Universities

If the interactions are observed from the viewpoint of universities, methodological problems of a different nature arise, although they lead us in the same direction.

• A common critical assumption is that traditional commercial indicators are insufficient for measuring the wide spectrum of potentially productive contributions in universities (Gulbrandsen and Slipersaeter 2007). Recent proposals are therefore directed at accounting for the largest number of possibilities. These studies underline the importance of considering the complete scope of university activities as a possible source of innovation for firms, including training and services. Indicator schemes of this type incorporate dimensions that encompass consultancy services, teaching, personnel flows as well as research and IPR exploitation (Molas-Gallart et al. 2002). Therefore those interactions that are most active in generating or using R&D results must be combined with those that involve utilizing the available university resources; be they human, facility-based, instrumental or expert protocols.

• Additionally, procedures set up by universities to keep track of professors' Third Mission activities, a role normally played by the technology transfer offices, are not usually sufficiently homogenous or detailed (Jones-Evans et al. 1999; Molas-Gallart et al. 2002). This is partially due to the fact that some of the relationships with firms without an IPR component are maintained by researchers directly and are not managed centrally. If the tracking systems the universities use do not, therefore, take those variations into account and do not encourage professors to provide the data, it means that a significant part of the cooperation mechanisms, apart from those that produce patents, remain hidden from university organizations. Consequently, there is a lack of research observing university participation in collaborative exchanges with a focus on individuals and research teams.

• In-depth analysis of the so-called "input indicators" for science, technology and innovation, based on the different versions of the Frascati Manual produced since the late 1960s, shows some of the limitations of the data they provide with respect to their quality and comparability, and also with regard to the information they contain and their degree of disaggregation (Godin 2005), which casts doubt on their utility for policy purposes in this area.

Following this line of thinking there is a movement in the specialized literature demanding that the range of observation be widened to allow the inclusion of results with respect to science policy, as well as the evaluation of university–industry collaboration. A methodological shift has been proposed towards "positioning indicators" (Lepori 2006; Lepori et al. 2008) generated by autonomous and strategic agents. The general approach is to describe the different actors in the system (researchers, intermediary institutions and research funders) by looking into their interactions of cooperation as well as competition (Barré 2006). Hence the importance of creating a set of ad hoc indicators adapted and interpretable as a function of the specificity of the context and the characteristics of the institutional structures. Finally, it is important to remember that indicators are considered as approximations and representations of reality and therefore they provide us with a partial view that should be completed with other types of complementary analyses.

Taking this discussion as a point of departure, the main thesis we put forward in our study is that, when observed closely, multiple interactions emerge that are not well identified in firm innovation studies and which usually go unreported in ordinary university registries. The different university–industry linkages generally are a product of the kind of knowledge associated with each specific activity. Therefore, bearing in mind that transfer processes use different channels, interactions will follow patterns that depend on the codified and tacit nature of knowledge. It can be expected that activities that involve the generation and use of scientific research will follow a different pattern from those related to the acquisition of skills and services. From a methodological standpoint, these assumptions have two important implications. First, the whole spectrum of possible knowledge exchanges between the two actors must be observed in order to capture the rationale behind university–industry relationships and to determine the role they play as sources of innovation. Second, observations and measures at a finer level of detail are required to illustrate the behavior of both firms and the scientific community.

This strategy is particularly appropriate for the study of the regional innovation system in Andalusia, where senior academics are able to establish cross-sector relationships with little central control. Accurate information about those interactions does not exist. University technology transfer offices do not use homogeneous protocols for gathering information, which makes it difficult to gauge the reach of Third Mission activities. Additionally, there are very few mid- and high-technology firms, which means that generation of patent licenses is not the main avenue of collaboration (CICE 2006). To the contrary, the most common collaborative activities between firms and universities are based on the use of services and the generation of tacit knowledge. The region, therefore, becomes a key site for testing a set of indicators by way of the two interacting actors.

Methodology

Our methodology is based on primary source data obtained using surveys that we conducted in 737 firms and 765 research teams in Andalusia in 2008.

Data sources, samples and field work

Firms

We used a registry of firms compiled by regional government agencies (Network of Technological Areas of Andalusia—RETA). It comprises 1,844 firms which have either received some type of public aid for innovation in the period extending from 1999 to 2005, or that have indicated interest in receiving innovation advice. Our source does not represent the population of all firms from the region, but only those with a more potentially innovative profile. We assume that this entails a certain bias when it is compared to the whole industrial sector.[2] Nevertheless, this decision facilitates an analysis of the characteristics of their cooperation. If we used a set of firms selected randomly from the total number registered in the region we would get a very small percentage of all of those which have some kind of relationship with universities. For most firms it would make no sense to ask them detailed questions about the diverse types of interaction which would lead us to a situation similar to those of the general innovation surveys.[3] Therefore, we interpret this group of firms as an "operative population" which fits the goals of this study since it is the segment of the productive sector with a higher tendency towards collaboration.

[2] We must point out that the bias is only in one direction. The majority of the small firms in the region in low technology sectors are not represented. However, practically all of the technology intensive firms as well as those that carry out significant R&D activities, from the very large to the very small, have received public aid, at least tax breaks, and therefore are included in the data file that we use as our source.

[3] In the Spanish national innovation survey the companies that declared that they have some sort of collaboration in R&D with universities or public agencies in 2005 were 8% (PITEC 2005).

This data source does provide some additional advantages. First, it includes firms with differing innovative capabilities. Some have only received aid that is not related to R&D (for example, a computer network or a web-based sales system), whilst some others represent a highly scientific profile (for example, R&D projects for firms in the aerospace industry). This means that only a relatively small proportion of them have an R&D department. Second, it incorporates a broad range of activity areas and a diversity of sizes, from small family businesses to large firms. Third, firms are not concentrated in industrial centers or technology parks near universities, but dispersed among the diverse urban and rural areas of the region. In short, this is a data source which is suitable for observing the different patterns of relationships and the possible factors which operate within them.

A sample of 800 firms was selected from the above population. The selection was done randomly with a proportional distribution between strata, consisting of sector of activity, and province where the firm is located. The field work was done through face-to-face interviews at the firms' offices. After a first contact with the firm, respondents were chosen from one of the following positions depending on the size of the company and its internal organization: owner, executive director, R&D or innovation department manager, or manager of the department most closely related to innovation.

When firms declined to participate, a substitute sample, chosen randomly using the same criteria, was used. The acceptance rate in the first wave was 76%, and in the second wave was 72%. The total sample included 737 firms. The main characteristics of which are summarized in Table 1. The majority of these firms are independent whilst less a quarter belong to a corporate group. The number of employees reflects the average size of the firms in the region: 52% have 10 or fewer employees, only 14% have more than 50 employees. A significant proportion of the total can be considered start-ups: 24% have been created after the year 2000. Their geographical locations as well as their sectors of activity are diverse. As far as innovation capability is concerned, 21% have an R&D department within the firm and 4% have one outside.

Universities

The public R&D system in Andalusia runs a registry of research teams which is used by the regional government to allocate R&D funding to researchers and, at the same time, to gather information from the scientific community. A research team is defined as a "a stable group formed by one or more scientific leaders, several researchers, young people on training internships and technical support personnel, that share technical-scientific goals, resources, infrastructure and equipment, with joint participation in research, development and innovation projects in collaboration with firms or public organizations" (CICE 2006). Since practically the entire scientific community is organized in research teams and registered, it is believed that using them as the unit of analysis makes it easier to observe Third Mission activities.[4] It is our view that research teams, by including people from all professional categories from research assistants to full professors, provide better coverage than a survey targeting individuals.

[4] The registry of research teams covers more than 90% of the scientific community in the public sector. The regional university system consists of nine public universities that employ close to 17,000 professors and researchers in all of the university categories (Fernández-Esquinas et al. 2008), together with 1,200 which are part of public research organisations (CICE 2006). Researchers that are part of bodies outside of the public sphere or those that do not realize year on year activities in said groups are not included in the registry.

Table 1 Characteristics of the firms in the sample

	Frequency	Percent
Belongs to a corporate group		
Yes	168	22.8
No	567	76.9
No answer	2	0.3
Number of workers		
From 1 to 5	225	30.5
From 6 to 10	162	22.0
From 11 to 25	174	23.6
From 26 to 50	73	9.9
More than 50	101	13.7
No answer	2	0.3
Mean	56	
SD	239	
Firm age		
Fewer than 7 years	133	18.0
More than 7 years	599	81.3
Do not know/no answer	5	0.7
Mean	18	
SD	21	
Activity sector (PITEC)		
Agriculture, livestock farming, forestry and fishing	46	6.2
Oil industry	3	0.4
Manufacture industry	196	26.6
Energy and water	26	3.5
Building industry	47	6.4
Services	419	56.9
Geographic environment		
Science or technology park	61	8.3
Industrial park	209	28.4
Urban area	398	54.0
Rural area	60	8.1
Others	6	0.8
Do not know/no answer	3	0.4
R&D department		
Yes, in this location	157	21.3
Yes, in a different location	28	3.8
No	551	74.8
No answer	1	0.1
Number of workers in the R&D department		
Fewer than 5 workers	102	55.1
From 5 to 9 workers	34	18.4
10 or more workers	38	20.5
Do not know/no answer	11	5.9
Not applicable	552	
Total	737	

The reference population is made up of 1,769 research teams registered in 2006. The regional government has provided the name of the leader and other basic information. For our purposes the research teams were separated using two criteria: the type of entity in which they practice their activity—universities, institutes that are part of the Spanish National Research Council, hospitals or other regional government centers—and the nine disciplines they are inscribed in.

A total of 800 research teams were chosen, stratified using proportional allocation based on the nine scientific areas. A simple random selection in each stratum resulted in a proportional distribution of the sample by types of center and scientific field in the region. The survey was conducted using a personal interview at the workplace of the team director or, in his absence, another member assigned by him. A total of 765 people responded to the survey, giving a response rate of 95%. The characteristics of the sample can be seen in Table 2. The majority are teams from universities (89%), since these have the greatest weight in the public regional R&D system. With regard to the areas of knowledge, they can be placed in "Humanities and Artistic Creation" (28%), followed by "Health Science and Technology" and "Social Science, Economics and Law" (both with 13%) and "Experimental Sciences" (11%). The majority of the teams are mid-sized: between 6 and 10 members (43%) and between 11 and 15 members (24%). These are well established groups since half of them have been together for between 11 and 20 years.

Indicator set

During the selection process for the indicators it was deemed necessary to adapt the different possible relationships between universities and firms to the survey field work. First, a long list of knowledge transfer activities was created based on a review of the literature. After doing several pre-tests, 12 were chosen. Interactions that are so specific that they only correspond to a scientific specialty or to a sector of activity, and therefore have very low frequencies, were added to categories of a similar collaboration type. Nevertheless, in addition to the pre-codified list of indicators, the survey permitted an open option of "other types of collaboration" which was assigned by the interviewer and codified afterwards.

The indicator set considers four groups: (a) R&D activities and formal consulting work, (b) training and transfer of personnel, (c) commercialization related to IPR, (d) other contacts (see Table 3). Those groups are divided into 12 types of possible relationships. Additionally, in the case of research teams, number thirteen was added to include non-academic knowledge diffusion activities since these are more frequent in the group of researchers. For each type both firms and research teams are asked if they had this relationship in the seven previous years (2000–2007) and the number of times. In short, this formulation makes it possible to contrast the same activity for each of the two actors.

Findings: mapping university–industry interactions

Firms

The different interactions that firms maintain with universities are summarized in Table 4. It is interesting to note that the highest scores (both percentage and mean value) are for the informal nexus (32% of the enterprises indicate that they participate in such networks) followed by "Training of university postgraduates and internships at the firm" (27%). This

Table 2 Characteristics of the research teams in the sample

	Frequency	Percent
Type of center		
Universities	683	89.3
Spanish National Research Council Centers'	39	5.1
Hospitals	31	4.1
Other research centers of the Andalusian government	12	1.6
Scientific field		
AGR—Agri-food	51	6.7
BIO—Biology and Biotechnology and Life Sciences	60	7.8
CTS—Health Science and Technology	105	13.7
FQM—Experimental Sciences	90	11.8
HUM—Humanities and Artistic Creation	220	28.8
RNM—Natural Resources, Energy and Environment	63	8.2
SEJ—Social Sciences, Economics and Law	103	13.5
TEP—Production and Construction Technologies	41	5.4
TIC—Information Science and Communications Technologies	32	4.2
Number of members		
From 1 to 5	77	10.1
From 6 to 10	331	43.3
From 11 to 15	185	24.2
From 16 to 20	88	11.5
From 21 to 25	40	5.2
More than 25	42	5.5
Do not know/no answer	2	0.3
Mean	12.2	
SD	7.7	
Research team age		
Up to 5 years	89	11.6
From 6 to 10 years	158	20.7
From 11 to 15 years	187	24.4
From 16 to 20 years	195	25.5
More than 20 years	122	15.9
Do not know/no answer	14	1.8
Mean	14.1	
SD	7.1	
Total	765	

last case is especially relevant since the regional government provides considerable policy support for this form of interaction. Moreover, it is a common way of discovering future employees and eliminates the pitfalls of personnel selection processes. The rest of the collaborative activities can be divided into three groups. Percentage of firms in each

Table 3 Types of interaction

Domains	University–industry collaboration
(a) R&D activities and formal consulting work	1. Consultancy work from a university or public research center
	2. Commissioned R&D projects (financed exclusively by the firm)
	3. Joint R&D projects (shared financing or with public support)
(b) Training and transfer of personnel	4. Training of postgraduates and internships at the firm
	5. Temporary exchange of personnel
	6. Specific training of the firm workers provided by the university
(c) Commercialization related to IPR	7. Use or renting of facilities or equipment
	8. Exploitation of a patent or utility model/joint patents
	9. Creation of a new firm (spin-offs and start-ups)
(d) Other contacts	10. Participation in a joint venture of hybrid research centre[a]
	11. Informal relationships
	12. Other types of collaborative activities
	13. Non-academic knowledge diffusion activities[b]

IPR intellectual property rights

[a] Direct participation in a new R&D organization, usually with government support

[b] Only for research teams

relationship, and the mean for the number of times they participate in each type of collaborative activity during the period of reference show the same pattern:

- Consulting activities, joint research projects and the training of firm workers by the university are carried out by between 15 and 25% of all firms.
- Between 5 and 15% of firms are doing commissioned R&D projects (contract research), using university facilities and participating in personnel exchange.
- Less than 5% of the firms have participated in spin-offs or start-ups, licensing or sale of patents and joint ventures.

Other types of collaborative activities such as participation in meetings, seminars, diffusion, and publications are carried out by not more than 2% of firms.

The importance of training contracts and consultancies is worth noting. Exploitation of intellectual property is clearly a minority activity even in those firms which could be considered as the most innovative in the region. Overall, 421 (57%) firms state that they have no type of collaboration and 305 (41%) firms that they have some type of collaboration beyond informal relationships. Eleven firms declare having only informal relationships, meaning that this indicator shows that the relationships are most generally linked to the other activities.

The second part of the analysis was done using 10 variables, excluding the informal relationships and those in the miscellaneous category which do not have specific contacts.[5] We employed a factor analysis using dichotomous variables which indicate if each type of interaction exists or not with values of 0 and 1. Similar analysis with the interval variables for the same items did not result in any meaningful aggregation pattern.

Table 5 shows the underlying structure of the university–industry relationships and reveals the existence of common patterns of interactions. R&D projects and consulting are grouped together. Those indicators related to training and exchange of personnel also form

[5] For this part of our analysis, the firms that exclusively indicated that they have informal relationships or other types of non-specific interactions have been added to the group which had no relations at all.

Table 4 Participation of firms in collaborative activities

	% Answering "yes" in each type of interaction	% Do not know/no answer	Collaborative intensity: number of interactions					
			N	Max.	Mean[a]	SD[a]	Mean[b]	SD[b]
Consultancy work	21.8	0.1	124	80	7.1	11.0	1.3	5.4
Commissioned R&D projects to universities	14.0	0.0	87	20	3.6	3.5	0.4	1.7
Joint R&D projects	22.1	0.0	145	33	3.8	4.8	0.8	2.6
Training of postgraduates and internships at the firm	27.5	0.1	158	147	8.1	16.0	1.8	8.4
Exchange of personnel	7.1	0.1	40	20	4.3	4.5	0.2	1.4
Training of firm workers by the university	15.2	0.5	93	40	4.1	5.0	0.5	2.3
Use or renting of facilities or equipment	8.1	0.1	48	48	4.6	7.3	0.3	2.2
Patent exploitation or joint patents	4.6	0.5	28	8	2.5	2.5	0.1	0.7
Participation in spin-offs and start-ups	3.9	0.3	27	100	5.4	19.0	0.2	3.7
Joint-ventures with universities	3.7	0.1	22	2	1.1	0.3	0.0	0.2
Informal relationships	32.2	0.8	147	100	8.2	14.5	1.9	7.7
Other types of collaborative activities	1.9	15.8	–	–	–	–	–	–

[a] Base: firms displaying at least one type of interaction

[b] Base: total of firms

an identifiable component. This is equivalently true for participation in the creation of a new firm (spin-offs and start-ups) or joint venture (although these actions are somewhat associated with the exchange of personnel too). Lastly, there are two specific activities which are clearly separated: exploitation of patents and the use of university facilities or equipment. The five resulting factors have been named after their characteristics:

F1: "Knowledge creation and application" (R&D projects and consulting)
F2: "Participation in starting a new organization" (joint ventures, new firms)
F3: "Training and exchange of human resources"
F4: "Exploitation of intellectual property"
F5: "Use or renting of facilities or equipment"

Universities

Table 6 shows the participation of research teams in collaborative activities. Again, informal links (45%) stand above the rest. The other indicators can be grouped in three categories:

- A high number perform expert consulting for firms (38%) and research projects commissioned by firms (34.8%). Teams that do joint research (30.6%) also stand out, in the same proportion as those that organize non-academic knowledge diffusion activities with firms (meetings, conferences, fairs, etc.).
- Second, there is a notable presence of activities related to human resources which flow both ways: specific training taught by the research teams to a firm (24.2%), internships

Table 5 Factor analysis of the types of interaction by firms. Rotated Component Matrix

	Components[a]				
	1	2	3	4	5
Consultancy work	**0.766**	−0.049	0.249	0.117	0.184
Commissioned of R&D projects to universities	**0.783**	0.096	−0.002	−0.061	0.062
Joint R&D projects	**0.715**	0.166	0.133	0.189	−0.141
Training of postgraduates and internships at the firm	−0.037	0.284	0.365	**−0.644**	−0.244
Exchange of personnel	0.070	0.415	**0.609**	0.113	0.095
Training of firm workers by the university	0.246	−0.077	**0.838**	−0.025	0.046
Use or renting of facilities or equipment	0.072	0.121	0.087	0.002	**0.933**
Patent exploitation or joint patents	0.161	0.198	0.213	**0.720**	−0.137
Participation in spin-offs and start-ups	−0.038	**0.626**	0.252	0.329	0.163
Joint-ventures with universities	0.214	**0.833**	−0.054	−0.152	0.015

Values for each type of interaction: 0 "No interaction", 1 "At least one interaction"

Extraction method: Main Components Analysis. Rotation method: Varimax with Kaiser normalization

[a] % Of variance explained: 68.8%

Bold values highlight the main variables contributing to each factor

of research team members in firms (20.4%), and exchange of scientific and technical personnel (12.4%).

- Participation in the exploitation of patents occur in 10.1% of the cases, being more common than renting facilities or equipment (8.4%) and the creation of spin-offs or start-ups in collaboration with a firm (6.1%).

A total of 425 cases, or 55.5%, of the sample had participated in at least one of the types of collaborative activities with firms, not including informal relationships, in the period 2000–2007. Thirteen cases declared that they had only had informal contact and the number of research teams that had not participated in any type of cooperative relationship was 327 (42.7%).

As with the firms, we conducted a factor analysis and excluded the informal relationships and those that corresponded with other types of activities. The only meaningful result is the one that uses dummy variables which indicate the existence of a relation for each item (that is, the variables are equal to 1 if the research team participated in each type of collaborative activity and 0 otherwise). Table 7 shows the rotated component matrix used to interpret the factors. The first factor identifies activities related to human resources (specific training for firms workers, internships for postgraduates in firms, or personnel exchange), in addition to those that organize non-academic knowledge diffusion activities with firms. The second factor is made up of variables that include exploitation of patents, creation of spin-offs and joint research projects. The next factor comprises variables related to research projects commissioned by firms or consulting work for them. The fourth factor is equivalent to renting facilities or equipment and the last one is the creation of a joint venture of a new R&D hybrid centre with the participation of both firms and academics. The five factors have been assigned the following denomination in accordance with the characteristics of the activities they contain:

F1: "Training and exchange of human resources and knowledge diffusion"
F2: "Commercialization: patents, spin-offs, and joint R&D projects"

Table 6 Participation of research teams in collaborative activities

	% Answering "yes"	% Do not know/no answer	Collaborative intensity: number of interactions					
			N	Max.	Mean[a]	SD[a]	Mean[b]	SD[b]
Consultancy work	38.0	0.0	291	100	3.7	8.9	2.1	7.0
Commissioned R&D projects from firms	34.8	0.0	266	70	3.2	6.2	1.8	4.9
Joint R&D projects	30.6	0.0	234	35	1.5	2.7	0.9	2.1
Training of postgraduates and internships at a firm	20.4	0.4	156	20	1.1	2.2	0.6	1.7
Exchange of personnel	12.4	0.0	95	15	0.7	1.9	0.4	1.5
Training of firm workers by the university	24.2	0.3	185	50	1.6	3.6	0.9	2.9
Use or renting of facilities or equipment	8.4	0.0	64	20	0.5	2.0	0.3	1.5
Patent exploitation or joint patents	10.1	0.3	77	100	0.6	4.9	0.3	3.7
Participation in spin-offs and start-ups	6.1	0.0	47	4	0.1	0.4	0.1	0.3
Joint ventures with firms	2.4	0.0	18	2	0.0	0.2	0.0	0.2
Informal relationships	45.0	0.0	421	100	3.7	7.8	2.1	6.2
Other types of collaborative activities	2.7	3.3	21	–	–	–	–	–
Non-academic knowledge diffusion activities	30.6	0.0	234	50	2.3	4.7	1.3	3.7

[a] Base: research teams displaying at least one interaction

[b] Base: total of research teams

F3: "Services for firms: commissioned research projects and consulting work"
F4: "Use or renting of facilities or equipment"
F5: "Joint venture of hybrid research centers"

Discussion

Previous research has emphasized the need for adequately measuring Third Mission activities because existing indicators are not sufficient, and those only centered on commercialization poorly reflect the possible socioeconomic impact of the knowledge flows between universities and firms. These are the two main reasons why our selected indicators can offer a better vision of this complex and non-linear phenomenon. Our case study provides further insight on this issue resulting from a comprehensive approach which consists of the application of a complete array of pre-tested indicators. The indicators are operationalized through two parallel surveys targeted to the participating actors: firms and research teams at universities, which taken together make a powerful measure. In fact, this represents an important contribution to collecting comparable information between universities and firms. The evidences are taken in the context of a catch-up region, which adds extra interest because of the extrapolation of the results to other similar regions worldwide.

When we connect the results obtained for both actors the first thing we notice is that participation in collaborative activities is far from a generalized practice, since around half—more in the case of firms (57%) and a bit less in the research teams (42.7%)—do not participate in any type of interaction whatsoever. It is, therefore, a phenomenon with ample

Table 7 Factor analysis of the types of interaction by research teams. Rotated Component Matrix

	Components[a]				
	1	2	3	4	5
Consultancy work	0.143	0.207	**0.571**	0.286	0.148
Commissioned R&D projects from firms	0.065	0.000	**0.848**	−0.048	−0.011
Joint R&D projects	0.187	**0.584**	−0.138	0.151	0.267
Training of postgraduates and internships at a firm	**0.674**	0.146	−0.161	0.183	0.203
Exchange of personnel	**0.514**	0.274	0.047	0.299	0.008
Training of firm workers by the university	**0.740**	−0.060	0.153	−0.134	−0.087
Use or renting of facilities or equipment	−0.064	0.017	0.092	**0.881**	−0.041
Patent exploitation or joint patents	0.004	**0.789**	0.078	−0.062	−0.233
Participation in spin-off and start-ups	0.085	**0.616**	0.161	0.023	0.092
Joint ventures with firms	0.023	0.028	0.096	−0.047	**0.930**
Non-academic knowledge diffusion activities	**0.561**	0.086	0.211	−0.227	0.009

Values for each type of interaction: 0 “No interaction”, 1 “At least one interaction”

Extraction method: Main Components Analysis. Rotation method: Varimax with Kaiser normalization

[a] % Of variance explained: 59.2%

Bold values highlight the main variable contributing to each factor

room for growth. Another common outcome stems from the importance that informal relationships play. Contacts that occur in different kinds of events are the breeding ground for future interchanges. This follows the line of thinking that states that knowledge creation and application is a socially embedded process, where interpersonal networks may act as a prior step and as a source of inter-organizational relationships (Perkmann and Walsh 2007). However, this aspect has scarcely been considered in empirical analysis. Nor has attention been paid to the non-academic diffusion that research teams actively develop and which contributes to knowledge transfer in a broad sense. Additionally, a considerable number of the exchanges are grouped under human resources that act in both directions although not in the same proportion suggesting that knowledge acquisition and transfer of skills are beneficial for both partners. In the university domain, specific research and consulting services are provided based on business demand and have become a clear outside source of innovation. Joint research, on the other hand, has an intermediate relative weight, which may reflect the inherent difficulties of this type of relationship which requires converging interests and a greater degree of adaptation to the distinct characteristics of the partner. Finally, the low incidence of patents and the creation of spin-offs in both cases—firms and universities—has been confirmed.

The results shed some light on the validity of the set of indicators applied. First, if they are too generic they do not provide valuable information when balanced against detailed measures (for example, informal relationships). Second, indicators which refer to minority activities which have no meaning for many of the aimed population are not very useful for further inquiry when used in a survey. Therefore, balance is needed between the level of specificity and the general scope of categories suitable to the majority. This is due to the coexistence of different scales in the multiple types of university–industry interactions. Third, the quantitative indicators that ask about the frequency of a relationship in a specific period do not usually provide good results in the analysis. The most consistent indicators are dummy variables referring to the existence, or the absence, of participation in collaborative linkages. These measures show comparable behavior seen from the point of view of the two actors involved.

The factor analysis carried out with these variables has shown that the relationship structure follows similar patterns in both cases with some slight differences. This reinforces our original assumption with regard to the existence of multiple interactions that, normally, neither the business innovation studies nor the university registers are able to identify. The usefulness of a wide set of indicators to view the real scope of the phenomenon and the most common routes university–industry relationships take has, as such, been confirmed. The methodological design employed and the field work undertaken let us delve more deeply into the behavioral patterns of each of the actors and contrast the results from both viewpoints by seeking information directly from the players. Their testimony reveals the complexity of cooperative links and shows us logical paths of action in line with intersecting individual and collective strategies. Some practices (such us renting others' facilities or equipments as well as exchanges related to human resources) become of mutual functional interest in inter-organizational exchanges. At the same time, some research teams at universities provide highly developed professional services in terms of research and consulting work to firms. Joint commercialization activities are scantly spread among the actors, but it portrays a specific path some follow. In the case of academics, IPR interactions are associated to joint research projects, meaning that for them coming together for a common goal leads more easily to assimilation of commercial behavior and bringing scientific discoveries into market. Therefore, transfer knowledge processes between universities and industry occurs indeed through a variety of mechanisms, revealing differences in the extent to which both actors engage in (Geuna and Muscio 2009). At the same time, there are high levels of heterogeneity in a regional environment. Further research is then needed on the components and factors influencing the types and levels of interactions.

Conclusions

This study supplies relevant information on university–industry collaboration in a catch-up region and some interesting observations which give cause for reflection on the suitability and possible improvement of the Third Mission indicator systems currently in use. First, this is a complex phenomenon which contains many variations and different scale interactions. When detailed indicators are used, such as in our case study, a range of diverse interactions appear, which often are difficult to identify and differentiate. A majority of them have little relation to R&D activities or IPR. Thus, the findings support the thesis that universities play a significant role as tacit knowledge suppliers.

Our analysis also shows the relevance that universities hold for the productive sector and how firms turn to them as a source of innovation. The resources they provide to each other are varied in nature and their use is dissimilar depending on the available effective possibilities as well as the strategies and priorities of the actors. The aggregation patterns of the different modes of interaction reveal the importance of the specific knowledge they exchange. This would explain why activities closely linked to R&D are widespread only in those innovation systems with high level research and high-tech business sectors. Besides, those activities focused on R&D, especially the exploitation of IPR, are conceivably just the tip of the iceberg and only emerge when absorptive and exploitation capacities exist, which were acquired through a wide range of contacts with universities. This is applicable to catch-up regions, although it can also be extrapolated to other more knowledge intensive environments.

Other conclusions to be drawn for Third Mission indicators are the need to use suitable data as well as theoretically guided measures which broaden the scope of observation of actors' motivations. As Lepori indicates with respect to indicators (2006, p. 142) "it becomes perfectly acceptable to make ad hoc choices and estimates when needed, provided that they are justified by reasonable arguments and are reported so that future analysts could also test different assumptions". Hence, flexible indicators become essential in adapting to an increasingly complex reality: employing non-aggregated analysis units makes this complexity visible. We must observe the position of the actors in the R&D system and the array of factors intervening in the multiple interconnections between universities and industry in order to move forward in our analyses of the links which join them. Only in this way will it be possible to have a more precise understanding of the surrounding reality and, consequently, make empirical contributions that can constitute new advances in Third Mission policy activities.

The findings suggest the need for systematic studies which probe the inner workings of the initiatives that promote cooperation and pay more attention to the different existing types of interactions, as well as the factors that push universities and firms towards collaboration. Only with a good grasp of the interconnection mechanisms and the processes of creation, maintenance and success of the nexus is it possible to adequately evaluate and redirect the stimulation policies which are normally unidirectional and indiscriminate, and as a consequence, inefficient and of limited impact. Other influencing factors, such as the individual characteristics of the researchers and the availability of social capital, become important in determining whether some relationships are more fruitful than others. Therefore, the need to combine statistical based macro-analysis with micro-analysis to contrast conclusions based on in-depth study of representative cases seems to be recommended.

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References

Arundel, A., & Geuna, A. (2004). Proximity and the use of public science by innovative European firms. *Economics of Innovation and New Technology, 13*(6), 559–580.

Barré, R. (2006). Towards a European STI Indicators Platform (ESTIP), position paper to the Second Prime Network of Excellence Annual Conference.

CES, Consejo Económico y Social de Andalucía. (2008). Informe sobre la situación socioeconómica de Andalucía 2007. Sevilla: Junta de Andalucía.

Chiesa, V., & Manzini, R. (1998). Organizing for technological collaborations: A managerial perspective. *R&D Management, 28*(3), 199–212.

CICE. (2006). *Plan andaluz de investigación, desarrollo e innovación tecnológica*. Sevilla: Servicio de Publicaciones, Consejería de Innovación, Ciencia y Empresa.

Cohen, W. M., Nelson, R. R., & Walsh, J. (2002). Links and impacts: The influence of public research on industrial R&D. *Management Science, 48*, 1–23.

Colyvas, J. A., & Powell, W. W. (2006). Roads to institutionalization: The remaking of boundaries between public and private science. *Research in Organizational Behavior, 27*, 305–353.

D'Este, P., & Patel, P. (2007). University-industry linkages in the UK: What are the factors underlying the variety of interactions with industry? *Research Policy, 36*, 1295–1482.

Etzkowitz, H., Webster, A., Gebhardt, C., & Terra, B. (2000). The future of the university and the university of the future: Evolution of ivory tower to entrepreneurial paradigm. *Research Policy, 29*, 313–330.

Fernández-Esquinas, M., Espinosa-de-los-Monteros, E., Jiménez-Buedo, M., Pérez-Yruela, M., & Ramos-Vielba, I. (2008). *Prospectiva de recursos humanos en el sistema andaluz de universidades*. Córdoba: IESA-CSIC/Consejería de Educación, Ciencia y Empresa.

Fernández-Esquinas, M., Ramos-Vielba, I. Jiménez-Buedo, M., & Espinosa-de-los-Monteros, E. (in evaluation, 2009). Unfolding the complexity of interactions between industry and university, R&D Management.

Geisler, E. (1995). Industry-university technology cooperation: A theory of inter-organizational relationships. *Technology Analysis and Strategic Management, 7*(2), 217–229.

Geuna, A., & Muscio, A. (2009). The Governance of knowledge transfer: A critical review of the literature. *Minerva, 47*, 93–114.

Godin, B. (2005). *Measurement and statistics on science and technology: 1920 to the present*. London: Routledge.

Godin, B., & Gingras, Y. (2000). The place of universities in the system of knowledge production. *Research Policy, 29*, 273–278.

Gulbrandsen, M., & Slipersaeter, S. (2007). The third mission and the entrepreneurial university model. In A. Bonaccorsi & C. Daraio (Eds.), *Universities and strategic knowledge creation* (pp. 112–143). Cheltenham: Edward Elgar.

Hicks, D., Breitzman, T., Olivastro, D., & Hamilton, K. (2001). The changing composition of innovative activity in the US: A portrait based on patent analysis. *Research Policy, 30*, 681–703.

Howells, J., Nedeva, M., & Georghiou, L. (1998). *Industry-academic links in the UK: A report to the Higher Education Funding Councils of England, Scotland & Wales*. Manchester: PREST.

Jones-Evans, D., Klofsten, M., Andersson, E., & Pandya, D. (1999). Creating a bridge between university and industry in small European countries: The role of the Industrial Liaison Office. *R&D Management, 29*(1), 47–56.

Laursen, K., & Salter, A. (2004). Searching high and low: What types of firms use universities as a source of innovation? *Research Policy, 33*, 1201–1215.

Lepori, B. (2006). Methodologies for the analysis of research funding and expenditure: From input to positioning indicators. *Research Evaluation, 15*(2), 133–143.

Lepori, B., Barré, R., & Filliatreau, G. (2008). New perspectives and challenges for the design of S&T indicators. *Research Evaluation, 17*(1), 33–44.

Mansfield, E. (1995). Academic research underlying industrial innovations: Sources, characteristics, and financing. *Review of Economics and Statistics, 77*(1), 55–65.

Martin, B., Salter, A. Hicks, D. Pavitt, K. Senker, J. Sharp M., & Von Tunzelmann, N. (1996). *The relationship between publicly funded basic research and economic performance. A SPRU review*. Report prepared for HM Treasury. Brighton: SPRU.

Meyer-Krahmer, F., & Schmock, U. (1998). Science-based technologies: University-industry interactions in four fields. *Research Policy, 27*(8), 835–851.

Mohnen, P., & Hoareau, C. (2003). What type of enterprise forges close links with universities and government labs? Evidence from CIS 2. *Managerial and Decision Economics, 24*, 133–146.

Molas-Gallart, J., Saltar, A., Patel, P., Scott, A., & Duran, J. (2002). *Measuring third stream activities. Final report to the Russell Group of Universities*. Brighton: SPRU, University of Sussex.

Mowery, D., Nelson, R., Sampat, B., & Ziedonis, A. (2001). The effects of the Bayh-Dole Act on US academic research and technology transfer. *Research Policy, 30*, 99–120.

OECD. (1996). *Regions and cities in the new knowledge economy*. Paris: OECD.

OECD. (1998). *University research in transition*. Paris: OECD.

OECD. (2002). *Benchmarking industry-science relationships*. Paris: OECD.

OECD. (2007). *Higher education and regions: Globally competitive, locally engaged*. Paris: OECD.

OECD. (2008). Review of higher education institutions in regional development 2008-10: Andalusia in brief. Retrieved 16 May 2009, from http://www.oecd.org/document/55/0,3343,en_2649_35961291_42060855_1_1_1_1,00.html.

OECDE Secretariat. (1999). Trends in university-industry research partnerships. *STI Review, 23*(2). Special issue on Public/Private Partnerships in Science & Technology. OECD.

Owen-Smith, J., & Powell, W. W. (2004). Knowledge networks as channels and conduits: The effects of spillovers in the Boston biotechnology community. *Organization Science, 15*(1), 5–21.

Owen-Smith, J., Riccaboni, M., Pammolli, F., & Powell, W. W. (2002). A comparison of US and European university-industry relations in the life science. *Management Science, 48*(1), 24–43.

Pavitt, K. L. R. (2001). Public policies to support basic research: What can the rest of the world learn from US theory and practice? (and what they should not learn). *Industrial and Corporate Change, 10*, 761–779.

Perkmann, M., & Walsh, K. (2007). University-industry relationships and open innovation: Towards a research agenda. *International Journal of Management Reviews, 9*(4), 259–280.

PITEC. (2005). *La innovación en la empresa española*. Madrid: FECYT-SISE.

PITEC. (2007). The technological innovation panel. Retrieved September 2007, from http://sise.fecyt.es/Estudios/PITEC/PITECdatabase.pdf.

Polt, W., Rammer, C., Gassler, H., Schibany, A., & Schartinger, D. (2001). Benchmarking industry-science relations: The role of framework conditions. *Science and Public Policy, 28*(4), 247–258.

Santoro, M. D., & Gopalakrishnan, S. (2000). The institutionalization of knowledge transfer activities within industry-university colaborative ventures. *Journal of Engineering and Technology Management, 17*, 299–319.

Schartinger, D., Schibany, A., & Gassler, H. (2002). Interactive relations between university and firms: Empirical evidence from Austria. *Journal of Technology Transfer, 26*, 255–268.

Shane, S. (2002). Selling university technology: Patterns from MIT. *Management Science, 48*, 122–138.

Stockdale, B. (2002). *UK innovation survey*. London: Department of Trade and Industry.

Thune, T. (2007). University-industry collaboration: The network embeddedness approach. *Science and Public Policy, 34*(3), 158–168.

Woolgar, L. (2007). New institutional policies for university-industry links in Japan. *Research Policy, 36*, 1261–1274.