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# Personal ties in university-industry linkages: a case-study from Argentina

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**Abstract** Many previous studies have advanced in identifying different modes of interactions between public research organizations (PROs) and industry and in assessing their associated benefits. However, few studies have adopted a *social network perspective* to analyze the relation between the characteristics of social ties and actors and specific aspects of PROs-industry interactions. Based on case-study evidence of linkages formed by researchers from a medium-sized Argentinian university, we include the *strength of tie* as one of the driving factors in the selection of PROs-industry channels. Following Granovetter (Am J Sociol, 1360–1380, 1973) we assess the concept of *strength of tie* as a linear combination of friendship, trustworthiness, reciprocity of knowledge exchange, and frequency of interaction. Using econometric techniques we find that stronger ties motivate the selection of longer-term bi-directional modes of interactions which, in turn, create knowledge benefits for PROs. In contrast, weaker ties are good enough for service provision, which creates financial benefits for PROs. These findings bring to the fore the need to conceptualize PROs-industry collaborations holistically, including the relational, social and historical nature of these processes side by side with technical and legal processes.

**Keywords** University-industry linkages · Networks · Strength of ties · Channel of interactions · Developing countries · Argentina

**JEL Classification** O38 · I38 · I23 · D85 · L14 · O20

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## 1 Introduction

Universities and public research institutes (referred to here as public research organizations, PROs) are fundamental to national socio-economic development because they are key actors in the production of knowledge. The knowledge relations they establish with other actors within the country is of key importance for the good performance of the National Innovation System (NIS) (Lundvall 1992, 2010; Etzkowitz 1990; Etzkowitz and Leydesdorff 2000).

PROs-industry literature has found that universities can expand industry's capacity to solve specific and complex problems. These problems often demand a combination of technologies that firms cannot develop individually. Instead, they can contribute to finding solutions by interacting with researchers and drawing from the pool of knowledge and resources available at PROs (Patel and Pavitt 1995) Similarly, universities develop new laboratory instruments and analytical methodologies that are a fundamental input for the private sector (Rosenberg 1992) On the other hand, benefits may also reach the science and technology (S&T) public system when PROs link with the productive sector. These organizations apply theoretical developments in a specific industrial field; they have access to specific infrastructure or knowledge from the private sector that may be unavailable otherwise; and, of course, they can access funding opportunities from new sources to pursue their research projects.

In Latin America the literature often claims that industry demand in the region falls short in terms of knowledge sophistication either because the productive structure is not technologically very dynamic or because where a demand for technology exists it can be satisfied by importing machinery, inputs and know-how. This implies that knowledge exchange has mostly adopted the form of routine-type technical assistance services. It follows that firms obtain fewer benefits from PROs than they could, and that PROs have fewer opportunities for industrial applications of the scientific and technological knowledge they produce.

Since the 1990s, S&T policies in the region have led PROs to be more directly linked to productive needs. Liaison Offices (LO) within PROs created at that time went to great lengths to promote more creative and longer-term linkages. However, PROs still normally reach firms through certain specific modes, primarily related to human resource training, service provision in technical assistance or testing and quality monitoring (Dutrénit and Arza 2010) In contrast, channels that involve a two-way flow of knowledge, such as joint research and development (R&D), are rarer.

The general perception among PROs and industry actors in Latin America is that there exists a mismatch in their capabilities, motivations, and expectations in forming knowledge linkages (Dutrénit et al. 2010; Vega Jurado et al. 2011) This contributes to doubt that linking is worth the effort.

In this paper we will explore whether the strength of personal relation makes a difference when forming different types of knowledge linkages, which in turn drive different types of benefits. To this end, we will combine the social network literature with the PROs-industry literature that has studied the relation between channels of interaction and benefits. We will develop specific hypotheses to be tested using econometric techniques for data collected with case-study methodology of a medium-sized Argentinian university.

The paper is divided as follows: Sect. 2 describes the main historical characteristics of public–private interactions in Argentina; Sect. 3 develops our conceptual framework; Sect. 4 presents our research questions and hypotheses; Sect. 5 discusses research design and methodology; Sect. 6 presents the empirical results; and Sect. 7 offers some conclusions.

## 2 Historical characteristics of public–private interactions in Argentina

Although certain voices have clamoured since the late 1960s for the State to play a more active role in guiding research in S&T to respond more effectively to societal needs (e.g. Sábato and Varsavsky),[1] it was not until the 1990s that S&T public organizations were left with no choice but to interact with the private sector. However, while in the 1960s and early 1970s the problem of development was viewed as the result of technological dependency—with policy measures therefore oriented to regulate technology flows from abroad and to channel investment in S&T towards strategic targeted sectors—in the 1990s the flaw in the existing S&T system was identified as being the lack of connection to actors that would use that knowledge.[2]

Therefore, following international trends in S&T policy, new policy schemes and organizations were created to strengthen linkages to other key actors in the NIS. In this context, the National Agency for the Promotion of Science and Technology (ANPCyT) was created in 1996, to provide R&D subsidies to the private sector and to promote PROs-industry linkages through specific programmes, and to support public–private LO to manage technology transfer and knowledge interaction between public research groups and firms. The quantity of LO increased sharply. The first ones opened in the mid-1990s and by 2015 there were 391 LO in the country (see Fig. 1).

As reported by Lombera (2011), 59.4% of LO belong to public S&T institutions (including public universities), 20.9% belong to NGOs (5.5% related to the private sector and 15.4% related to the public sector), 9.9% are owned by companies and 9.9% belong to private universities. These LO are rather small (the average workforce is just seven people) and around 60% of their budget is funded by the host organization (the rest is self-funded). Moreover, half of the partners involved in agreements managed by LO come from Argentina and only 2% come from abroad (Lugones et al. 2015).

Since the last macroeconomic crisis (2001–2002), support for S&T production has continued to grow, as can be seen in the increase in investment in R&D shown in Fig. 2. Similarly, policy emphasis in promoting PROs-industry interaction has persisted.[3] For instance, new regulations to commercialize public research[4] came into effect in 2009.

[1] Varsavsky (1973), proposed what López (2007) called a linear model but "the other way around". He argued that society had to set the productive priorities from which technological needs were to be derived. Those needs should be satisfied by the S&T complex. In turn, Sábato and Botana (1968) developed the triangle model to emphasize the need for public policies to integrate the three vertexes: state, productive sector and scientific sector. Sábato's ideas set a precedent for the "triple helix" model of Etzkowitz and Leydesdorff (1997).

[2] In opposition to previous ideas, international knowledge was viewed as an opportunity for development. In fact, the 1990s marked a period of liberalization policies in Argentina. It was believed that trade liberalization would promote technological innovation due to the increase in foreign competition and the reduction in price of imported capital goods. Policies during this period also relied on foreign direct investment as a mechanism for successful technology transfer from abroad.

[3] See National Bicentenary Strategic Plan of Science, Technology and Innovation (2006–2010) and Argentina Innova 2020: National Plan for Science, Technology and Innovation. Strategic Guidelines 2012–2015.

[4] The content of these regulations was authorized by Article 19 of Law 25,467 (2001) but they were only enacted in 2009.

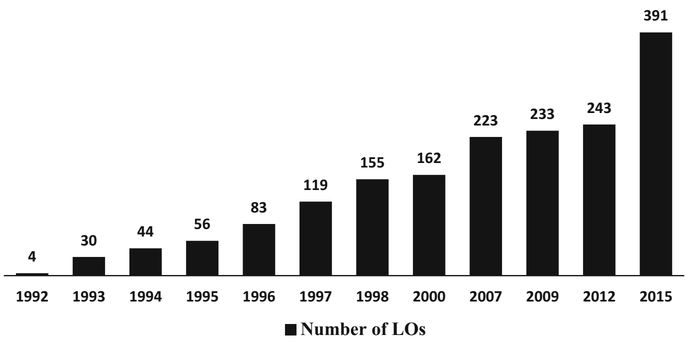


**Fig. 1** Evolution in the number of Liaison Offices (LOs) in Argentina (1992–2015). *Sources*: Muñoz et al. (1999), Kababe Y. (2010) and Ministry of Science, Technology and Innovation. Argentina. (2015)

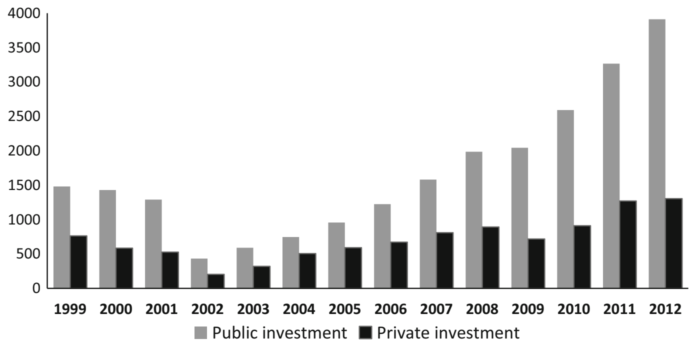


**Fig. 2** Investment in Research and Development in Argentina (1999–2012) (In millions of U$$). *Source*: Ministry of Science, Technology and Innovation. Argentina

As a result of these policies, PROs-industry interactions have shown an upward trend since the 1990s. Yet private involvement in performing and funding R&D and other innovative activities continues to be rather low (Fig. 2), even by regional standards. In 2012 (latest available figures) Argentinian firms participated in around 25% of total expenditure in innovative activities, a share clearly lower than that of Brazil (45%), Colombia (31%) and Mexico (38%), as can be seen in Fig. 3.

Another historic characteristic of the Argentinian S&T system is geographical concentration, which also reflects the geographical distribution of the national gross domestic product (GDP): in 2005, 67.4% of Argentinian GDP came from just three provinces—Buenos Aires, Santa Fe, Córdoba—and the Autonomous City of Buenos Aires (Argentinian Economy Ministry 2005). Similarly, the same regions in 2012 include 52% of existing national universities and 80% of trained researchers (SPU Yearbook 2012). Since PROs-industry linkages are highly localized, these geographical asymmetries can only be broken by long-distance knowledge interactions.

There are ample opportunities to enhance the performance of the NIS by improving knowledge networks. This has long been claimed by the specialized literature and has also been asserted by policy documents in Argentina. In this paper we explore how the strength of ties affects the selection of different modes of interactions, and in turn the type of benefits they would produce.

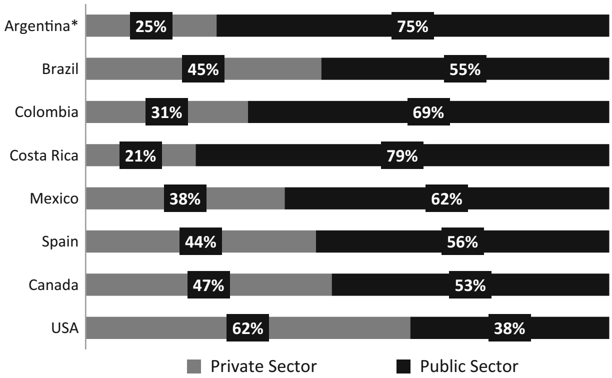


**Fig. 3** Composition of R&D by execution sector. Comparison between groups of selected countries (2011). *The data of Argentina, corresponds to 2012. *Source*: Ministry of Science, Technology and Innovation. Argentina

## 3 Conceptual framework

The literature on PROs-industry linkages could be divided into two types of approaches. Firstly, there are studies, mainly descriptive in nature, aiming at discussing how interactions work, the role of LO, interaction goals, the performance of science parks or other types of networks, etc. (e.g. Acworth 2008; Cohen et al. 2002; Kodama 2008; Lockett et al. 2008; Meyer-Krahmer and Schmoch 1998; Wright et al. 2008). These studies normally built taxonomies to organize modes of interaction according to common criteria: degree of formality in contractual arrangements (e.g. Bonaccorsi and Piccaluga 1994; Eun 2009; Romero 2007; Schartinger et al. 2002; Vedovello 1997, 1998); the goals sought by firms and PROs when signing agreements (e.g. Arza 2010; Kruss 2006); the level of coordination among stakeholders (e.g. Fritsch and Schwirten 1999; Perkmann and Walsh 2007); etc.

The second group attempts to analyse causes and consequences of link formation. Either they study firms' and/or PROs' characteristics that work as drivers for forming linkages (e.g. Fontana et al. 2006; Giuliani et al. 2010; Landry et al. 2007; Veugelers and Cassiman 2005) or they assess the effect of linkages in terms of benefits received by PROs and/or firms (e.g. Defazio et al. 2009; Monjon and Waelbroeck 2003; Owen-Smith and Powell 2003; Rothaermel and Thursby 2005). Within this second group, there are a few papers that have analysed the determinants or the relative effectiveness of different modes or channels of interactions on driving specific benefits. Some have focused on the relation between channels of interactions and firms' innovative inputs (Adams et al. 2003; Arvanitis et al. 2008b; Cohen et al. 2002) and some on firms' innovative outcomes (Arvanitis et al. 2008a; Eom and Lee 2009).

Along the same lines, a series of papers published in a special issue of *Science and Public Policy*,[5] compared the relative effectiveness of different channels of interaction in driving certain types of benefits for firms and PROs in four Latin American countries. All papers in this series use a single taxonomy to classify modes of interaction developed by Arza (2010) based on the goals firms and PROs pursue when interacting. Four channels of interaction were identified (bi-directional, commercial, traditional and service), while benefits were classified as short- and long-term. The framework predicted that the bi-directional channel produces long-term benefits for both firms and PROs, while the service

[5] See Arza and Vazquez (2010), for the Argentinian study, Fernandes et al. (2010), for Brazil, Orozco and Ruiz (2010), for Costa Rica, and Dutrénit et al. (2010), for the Mexican case study.

channel produces short-term benefits. Interestingly, results across countries were similar in terms of the characteristics of benefits triggered primarily by each type of channel.[6]

Building from Arza's (2010) taxonomy, this paper contributes to the second group of studies on PROs-industry interaction and combines it with social network literature, to assess the extent to which strength of ties is an important driver in explaining the selection of different channels of interactions.

The unit of analysis in the social network literature is the individual tie between nodes or actors (e.g. researcher groups, individual researchers, firms, organizations, research groups, etc.) forming social networks. In this literature the strength of ties is an important dimension in characterizing the interactions between nodes.

The importance of the concept is that the *strength of ties* usually has a predictive capacity about the content and exchanges that can potentially occur within a particular relationship (Granovetter 1973; Wellman 1982; Lin et al. 1981a, b).

Granovetter (1973, p. 1361) defines the strength of ties as "a (probably linear) combination of the amount of time, the emotional intensity, the intimacy (mutual confiding) and the reciprocal services which characterize the ties". Strong ties are based on trust, reciprocity and common interactions, while weak ties are defined as casual and infrequent contacts between individuals, based neither on trust nor reciprocity between the parties. Granovetter argues that in scientific fields, new information and ideas are more efficiently diffused through weak ties (Granovetter 1983). The reason is that individuals with weak ties act as a bridge for transmitting information and knowledge between closed communities and thus add new information. Groups of actors who are very close and who share similar values are usually more inclined to consensus rather than to question the status quo. This scenario is not very fruitful for the generation of new ideas. Many studies since Granovetter's have attempted to apply his hypotheses on the strength of weak ties to analyze knowledge exchanges. Filieri and Alguezaui (2014) review this literature and argue that the relationship between strength of tie and the outcomes of knowledge exchange is mediated by the type of knowledge being exchanged (i.e. tacit or codified) and the motivation driving inter-organizational interactions (i.e. to search for, access, assimilate, or create knowledge).

It is argued in the literature that weak ties are important for the search for, access to and diffusion of, essentially, codified, simple, and standardized knowledge (Hansen 1999; Reagans and McEvily 2003). Weak ties enable the network to expand and therefore knowledge becomes more widely disseminated. The literature found that weak ties are crucial in knowledge exploration and search processes (Uzzi 1996; Burt 2005), as they connect new and non-redundant areas of knowledge, create new ties of connection between actors previously disconnected and provide new resources to the network (Uzzi 1996).

On the contrary, strong ties are relevant in assimilating or creating (Tiwana 2008; Capaldo 2007; Smith et al. 2005) fine-grained and complex knowledge and information that is more detailed, deeper and specific in a particular interest area for the individuals involved (Levin and Cross 2004; Rowley et al. 2000; Uzzi 1996, 1997). These ties generate shared understandings, confidence and a common language over time (McFadyen and Cannella 2004; Kogut and Zander 1996; Nooteboom 2007). Strong ties are characterized by interpersonal relationships based on trust and frequent interactions, which facilitate coordination (McEvily et al. 2003) and promote the sharing of exclusive resources/knowledge among social actors in the network (Villanueva Felez et al. 2015; Mu et al. 2008; Szulanski 1996; Uzzi 1996; Krackhardt 1992). They therefore also restrict opportunistic behaviour (McFadyen and

[6] In a recent paper, Kruss (2012) used the same taxonomy to relate channel with benefits and also with risk of interactions for the biotechnology sector in South Africa.

Cannella 2005; Coleman 1990; Uzzi 1997) which is important in exchanging highly valuable (either symbolic or monetary) knowledge (Bouty 2000).

In short, weak ties are casual and infrequent links that normally connect actors that hardly know each other (or at least they do not have a relation based on trust and reciprocity). The social network literature shows that these links are nevertheless useful in diffusing existent and largely codified knowledge. In contrast, strong ties tend to be systematic and frequent links connecting actors that trust each other and have a relationship built on reciprocity. These types of linkages are needed to exchange tacit and complex knowledge.

There are some studies that combine the social network literature and the PROs-industry literature, as we do here.

The lion's share of these, mostly use the *context* of PROs-industry interactions to analyse the role of *strength of ties* on knowledge outcomes, as the social network literature has done for different contexts. For example, Fritsch and Kauffeld-Monz (2010) argued that strong ties are more favourable for knowledge exchanges in the context of regional innovation networks where universities and firms interact. Santoro and Saparito (2006) found that trust (a key feature of strong ties) facilitates knowledge exchange between universities and firms, especially when the knowledge is tacit; while Villanueva Félez and Molas Gallart (2011) claimed that the strength of tie is vital for exchanging new information. Similarly, Johansson et al. (2005) argued that strong ties are very useful for transferring complex knowledge between spin-offs and universities.

We found very few studies that inquire into the relation between *strength of ties* and aspects of interactions that have been studied specifically in the PROs-industry literature, such as those related to academic performance or to risks of knowledge misappropriation or to other conflicts that stem from differences in the socio-cultural background of interacting partners.

The role of the strength of ties on academic performance has been studied by Villanueva-Felez et al. (2013) and Balconi and Laboranti (2006). The former found that researchers who are part of an integrated network, with a mix of strong and weak ties, achieve better research results; while the latter argued that stronger connections are associated with high scientific performance. Other studies focused on conflicts of PROs-industry interactions and argued that the strength of ties could contribute to overcoming them. Bruneel et al. (2010) concluded that trust help in lifting some barriers, particularly those related to research orientation and intellectual property protection when they are tied in stronger relationships. Similarly, Bouty (2000) suggested that when the expected output of PROs-industry interactions have commercial value, partners are likely to be reluctant to exchange strategic resources unless the relationship is built on strong ties. Finally, McFadyen and Cannella (2005) also claimed that opportunistic behaviour is minimised if closeness and trust characterize the relation between partners.

As far as we are aware, there is no literature that has investigated the relation between strength of ties and the selection of different channels of PROs-industry interactions and their associated benefits. This is, we believe, the main contribution of this paper. We analyse firstly whether the strength of ties drives the choice of channel of interaction differently by answering the research question: *q1. Does the strength of ties affect the selection of the different PROs-industry channels?* Secondly, we analyse the extent to which the selection of different channels relates to the achievement of different benefits for researchers, by answering: *q2. What are the associated benefits of choosing different channels?*

## 4 Hypotheses development

We will use Arza's (2010) taxonomy of PROs-industry interactions which identifies four main channels of interaction:

(I) *Traditional:* This is the result of conventional PROs missions (i.e. teaching and research) and is the traditional way firms have historically benefited from PROs activities (e.g. hiring new graduates, or gaining information through conferences, publications, etc.) For PROs the main motivation for using this channel is intellectual, for firms it is to absorb knowledge that has already been created. Knowledge, therefore, flows mainly from PROs to firms. Personal interaction is not necessary and knowledge is sometimes codified in publications but other times it is embodied in the interacting researcher.

(II) *Services:* This channel includes the provision of scientific and technological services in exchange for money (e.g. consultancies, use of PROs equipment for quality control or testing, training firms' staff, etc.). Firms use this channel for a similar reason as for using the traditional channel, namely to get to know what is already known by other actors in the NIS. Technical knowledge can be diffused widely through this channel. For PROs the main motivation is to raise new funds. Knowledge flows mainly from PROs to firms. Personal interaction may or may not exist, and where it does, it lasts only as long as the provision of the service (i.e. usually for short periods). Much of the knowledge transmitted is mature, codified and can be transferred without intense face-to-face collaboration.

(III) *Commercial:* This channel allows PROs to market their research results (e.g. patents, technology licenses, spin-offs, incubators, etc.). For PROs the main motivation is to market their research outputs and, as a consequence, to obtain extra funds. For firms, it is to be proactively involved in innovation activities, creating new products or processes. Depending on the characteristics of the contractual agreement and the extent to which researchers engage in business activities or support, knowledge may flow in both directions. Personal interaction is usually required in the first stages of the relationship when parties have to agree on the type of knowledge that is being commercialized and may continue after, depending on the specific features of the agreement. Also, it is argued in the literature that this channel is more effective when systematic and direct relations between institutional members are established (Dahlstrand 1999).

(IV) *Bi-directional:* This channel allows knowledge to flow both ways strengthening the potential for joint learning. Interactions using this channel are generally motivated by researchers' scientific and academic ambitions (e.g. to generate new knowledge, to apply theoretical knowledge, etc.) and by firms' innovation strategies. This channel includes modes of interactions such as joint R&D, participation in networks, science and technology parks, etc. They usually involve personal contact. The relationships are generally formalized in long-term cooperation agreements. This channel involves a higher level of coordination than other channels, promoting the transmission of tacit knowledge.

Thus, the degree of personal interaction differs across different channels, being particularly important for the good performance of the bi-directional channel and for the first stages of the commercial channel. In contrast, the service channel does not normally require personal interaction to work properly (or this requirement has a short-time span), nor do most of the activities within the traditional channel require this.

Similarly, some channels are better for exchanging tacit, complex and new knowledge while others are more effective in transmitting codified and more mature knowledge, with the bi-directional channel standing out for the former and the service channel for the latter.

Since by definition the strength of ties is based on frequent and personal interaction and since the literature has claimed that these types are particularly suitable for exchanging tacit and complex knowledge, we propose the following research hypotheses for the first research question. Given data restrictions, we focus our analyses on the bi-directional and service channel.

**H.1.1**. The existence of strong personal ties is positively associated to the probability of choosing the bi-directional channel.

**H.1.2** The existence of weak personal ties is positively associated to the probability of choosing the services channel.

For the second research question, following Arza (2010) we classify benefits for PROs into:

(I) *Long-term (knowledge benefits)*: these occur when the quality of research and teaching is improved by learning in the application context or by learning about production technologies which may be useful for future research. Research may be inspired by industry applications and knowledge exchange with industry (Meyer-Krahmer and Schmoch 1998), which provides new insights for the research agenda (Fritsch and Schwirten 1999; Lee 2000; López-Martínez et al. 1994; Perkmann and Walsh 2008)

(II) *Short-term (financial benefits)*: these occur when new funding resources for infrastructure, staff or student support become available as a result of linking with the private sector. The literature confirms that obtaining extra funds (or diversifying sources of funds) is one important benefit of PROs-industry interaction (Geuna 2001; Lee 2000; Mendoza 2007; Meyer-Krahmer and Schmoch 1998; Azagra-Caro et al. 2006; Dasgupta and David 1994; Etzkowitz et al. 2005; López-Martínez et al. 1994; Nelson 2004; Perkmann and Walsh 2008; Slaughter and Leslie 1997).

Some channels of interactions are more effective in driving different types of benefits.

The provision of scientific and technological *services* in exchange for money, where knowledge flows mainly from PROs to firms (e.g. consultancy, use of equipment for quality control, testing and monitoring, etc.), may work particularly effectively in driving financial benefits. Similarly, when choosing to *commercialize* scientific outcomes, researchers and PROs are mainly motivated by their need to create economic value from scientific activities.

In contrast, PROs choose the *traditional* channel (e.g. producing graduates to be hired by industry or producing and disseminating research outputs at conferences or in publications) motivated mainly by their traditional intellectual activities of teaching and research. Similarly, researchers choose to spend time resources on the *bi-directional* channel (e.g. joint R&D, participation in networks, participation in science and technology parks, etc.) when they are particularly keen to learn from their counterparts.

As before, we focus on relations between bi-directional and service channels of interactions and benefits. The main hypotheses are:[7]

**H.2.1.** Interactions through the bi-directional channel is positively associated to the probability of obtaining knowledge benefits.

**H.2.2.** Interactions through the service channel is positively associated to the probability of obtaining financial benefits.

## 5 Research design and methodology

### 5.1 The case study

Our case study is the National University of Central Buenos Aires (UNICEN). This is a medium-sized university, fairly well integrated to production activities in the region where it is located. In 2012 it had 13,130 students and 2775 employees, distributed over ten faculties (i.e. schools). The university brings together some attractive characteristics that make it an interesting case for study.

Being a medium-sized university in terms of enrolment and budget, UNICEN represents in terms of size the reality of many of the national universities in Argentina better than other more renowned universities such as the University of Buenos Aires. Nonetheless, it has a clear profile in scientific and technological research: there is a high proportion of full-time professors (26% of the staff work solely at the university, compared to the national average of 12.4%) and a high proportion of PhDs (13.7% of lecturers have doctorates) in relation to the national average (9.6%).

Moreover, UNICEN shows a strong vocation for linking to its regional context. It has been a key player in the creation and development of the Tandil Information and Communication Technology Park, a pioneer initiative of its kind in the country, recognized as such by Camera of Software and Computer Services of Argentina. The Park has attracted over 60 domestic and international software and information technology services companies. In 2008, there were over 850 people working there (Rivero and Dabos 2011).

### 5.2 Data collection

We interviewed 46 principal researchers using a semi-structured questionnaire between May and August 2013. These represent 57% of all principal researchers working in the University. We identified 131 different PROs-industry linkages from 2010 to 2013. The questionnaire inquired into the research group characteristics (size, skills, education, research field); relational aspects of linkages with the private sector and main impacts and risks associated to those interactions. We complemented this data with public information about researchers' characteristics available at the UNICEN website.

[7] These hypotheses have been empirically tested in other case studies (see Arza and Vazquez 2010, 2012; Dutrénit and Arza 2010; Dutrénit et al. 2010; Fernandes et al. 2010; Orozco and Ruiz 2010).

### 5.3 Methodology

The unit of analysis is the individual tie between research groups from UNICEN and firms, as informed by researchers. All variables used in the analysis are fully defined in "Appendix 1". The research design included three different analyses.

The first analysis was to operationalize the strength of ties concept by Granovetter (1973). This concept continues to be relatively abstract in the literature; the few attempts that have tried to measure it empirically used a diversity of indicators including:

- Proximity or closeness of a relationship (Granovetter 1974; Lin and Dumin 1986; Murray et al. 1981), assuming that the *close friend* category indicates a *strong tie*, while the *acquaintances or friends of friends categories* indicate a *weak tie*;
- Frequency of contact (Granovetter 1974; Lin et al. 1978), assuming that *greater frequency* of contact implies a *stronger tie*;
- Mutual acknowledgement of contact (Friedkin 1980), assuming that ties that are recognized by both parties in a relationship are *strong ties*;
- Extent of multiplexity within a tie (Granovetter 1973) related to the overlapping of roles and memberships in partner organizations;
- Duration of the contact, assuming that longer-term relations mean *stronger tie (*Shi et al. 2009).

In this paper, inspired by Granovetter's definition, we proxied the concept of strength of tie as a linear combination of friendship, trustworthiness, reciprocity of knowledge exchange, and frequency of interaction. We asked researchers to assess their relationships with private partners in these four dimensions using a 5-point Likert scale. Each aspect, except frequency, was measured in an increasing scale. Frequency was measured as 1 for the most frequent and 5 for the least. Using factor analysis we constructed a synthetic indicator that accounted for the common variability of those four dimensions.

The second analysis uses the factor score as indicator of strength of ties to explain the relative probability of choosing different channels of interaction. To this end, we needed to classify interactions into the four channels proposed by Arza (2010) using information on modes of interaction as identified by researchers themselves. We had this information for 110 of the 131 identified interactions. Some examples to illustrate how we implemented the taxonomy are presented in *Table 1*. Due to data restrictions, in our estimations we only work with the service and the bi-directional channels.

As for estimation methods, we estimated logit, probit and linear probability models, to be able to test hypotheses 1.1 and 1.2, where the dependent variable adopted the value 1 for the bi-directional channel of interaction, and in turn, for the service channel of interaction, as can be seen in Eq. 1.[8] All models were estimated with clustered (by researcher) robust standard errors.

[8] We originally estimated a multinomial logit since our dependent variable was actually polytomous (there were four categories for the variable channel of interaction) and we were interested in analyzing whether the *strength of ties* inclines researchers and firms towards one or another channel of interactions. However, since there were too few observations in two of the four categories, we were forced to interpret our results for just one pair of relative probabilities (i.e. that which relates bi-directional with service channels.) Results were perfectly consistent with those found when estimating dichotomous probability models, which therefore are the ones we decided to report.

**Table 1** Modes of interactions involved in each channel

| Channel | Links | Percentage (%) | Integration type |
|---|---|---|---|
| Bidirectional | 26 | 24 | Long term research contracts<br>Participation in public–private research networks<br>Research and development projects (PID)<br>Scientific park |
| Commercial | 3 | 3 | Private financing of inputs for testing<br>Spin off<br>Patent |
| Service | 74 | 67 | Testing, trials<br>Technical assistance<br>Training staff<br>Consultancy<br>Personnel exchange |
| Traditional | 7 | 6 | Publications<br>Informal contacts<br>Conferences and exhibitions<br>Recently hired graduates |
| Total | 110 | 100 | |

$$\begin{aligned}\Pr\left(Ch_j\right) = {} & \alpha + \beta_{1ch\_\mathrm{j}} strengh\_ties + \beta_{2ch_j} prize + \beta_{3ch_j} size\_team + \beta_{4ch_j} fin\_motiv \\ & + \beta_{4ch_j} know\_motiv + \beta_{5ch_j} res\_\mathrm{init} + \beta_{6ch_j} disc\_agronomy + \beta_{7ch_j} disc\_science \\ & + \beta_{8ch_j} disc\_veterinary\end{aligned} \tag{1}$$

with *j*, being, alternatively: service and bi-directional.

Our indicator of strength of ties was the main explanatory variable and we also included other control variables informed by the received literature as important for channel selection, such as team quality proxied by received prizes, team size, motivations for interaction, discipline (school)[9] and the extent to which the research team had initiated the interaction. We tried different model specifications. Using Bayesian Information Criterion (BIC) we opted for that which better fit our data. All estimations were performed using clustered (by researcher) robust standard errors.

Finally, the third analysis aimed at testing hypotheses for the second research questions that relate channels of interactions with benefits. In doing so we also included the *strength of ties* and the time since researchers first met their counterpart (*link_age*) as explanatory variables for benefits of interacting.

Following the literature, we constructed indicators for two types of benefits. Unfortunately, our questionnaire did not disaggregate benefits by types of linkages, but rather accounted for the researchers' overall experience in linking with the private sector.

The indicator of financial benefit was built as a binary variable that informs on whether linking with the private sector improved the financial situation of research projects. The

[9] The researchers we interviewed came from five different schools: economics (3 researchers), exact science which includes information technologies (ICT) & physics (17), agronomy (20), veterinary (34), and engineering (52). We include a dummy for each with the latter being the base category. Since there were too few researchers from the school of economics we had to drop that category (i.e. researchers from that school were then by the default included as part of the base category).

indicator of knowledge benefits was in turn a binary variable accounting for those situations for which linking to the private sectors improved either teaching activities, or scientific reputation of research teams, or were recognized as important for researchers' careers.

Researchers and firms take into consideration the expected benefits of different types of interactions when choosing how to interact. Thus, we needed to account for this endogeneity when estimating the effects of channels of interaction on benefits of interacting. Two alternative estimation methods were used to control for endogeneity in Eq. (2).

Firstly, we use instrumental variable (IV) models with two stages least square estimation (2SLS) to control for endogeneity of channels of interactions.[10]

$$\begin{aligned} \Pr(know\_ben) &= \alpha + \beta_1 Ch_j + \beta_2 strength\_ties + \beta_2 link\_age \\ \Pr(fin\_ben) &= \alpha + \beta_1 Ch_j + \beta_2 strength\_ties + \beta_2 link\_age \end{aligned} \quad (2)$$

with $j$, being, alternatively: service and bi-directional.

Secondly, we estimate the Equation set 2 as part of a system of structural equations, with channels of interactions being endogenous variables among those explaining benefits of interactions. The endogenous explanatory variables are the dependent variables from Eq. (1) in the system. Thus, we estimated simultaneously Eqs. (1) and (2) using three-stage least squares (3SLS) estimation method. In fact, two systems were estimated separately for each of the two dependent variables in Eq. (2) (financial and knowledge benefits): one for the endogenous explanatory variables being the bi-directional interactions and, in turn, another system for service interactions.

## 6 Results

We organize the presentation of results by the three analyses defined in the methodological section.

### 6.1 Analysis 1: measuring strength of ties

We proxied the concept of strength of tie as a linear combination of friendship, trustworthiness, reciprocity of knowledge exchange and frequency of interaction (Granovetter 1973). Using factor analysis we constructed a synthetic indicator that accounts for the common variability of those four dimensions. The results are presented in Tables 2 and 3. Factor loadings have the correct sign in all cases (all positive except for frequency that was negative because it was defined as 1 for the most frequent and 5 for the least).

We extracted one single factor using the eigenvalue criterion (greater than 1) and we interpreted it as a latent variable accounting for the *strength of tie*. This factor explained 43% of the variation of original variables included in the analysis, which means that the latent variable is relatively successful in explaining the overall variability of variables associated to strength of tie in our dataset.

[10] Independent variables from Eqs. (1) and (2) were used as instruments robust cluster standard errors.

**Table 2** Factor analysis/correlation: Factors that affect the strength of tie

| | Factor analysis/correlation<br>Method: principal-component factors<br>Rotation: (unrotated) | | Number of obs = 120<br>Retained factors = 1<br>Number of params = 4 | |
|---|---|---|---|---|
| Factor | Eigenvalue | Difference | Proportion | Cumulative |
| Factor 1 | 1.72132 | 0.83450 | 0.4303 | 0.4303 |
| Factor 2 | 0.88682 | 0.10992 | 0.2217 | 0.6520 |
| Factor 3 | 0.77690 | 0.16192 | 0.1942 | 0.8463 |
| Factor 4 | 0.61497 | – | 0.1537 | 10000 |

LR test: independent versus saturated: $chi^2$ (6) = 37.19

Prob > $chi^2$ = 0.0000

**Table 3** Factor loadings (pattern matrix) and unique variances

| Variable | Factor 1 | Uniqueness |
|---|---|---|
| link_freq | −0.6337 | 0.5984 |
| link_friend | 0.5487 | 0.6989 |
| link_trust | 0.6701 | 0.5509 |
| link_recip | 0.7547 | 0.4305 |

## 6.2 Analysis 2: Strength of ties as driving factor for the selection of channels of interactions

In the second analysis we used the strength of tie to explain the probability of choosing, in turn, the bi-directional and the service channel. We estimated probit, logit and linear probability models. The results are shown in Table 4. All models fit our dataset quite reasonably ($R^2$ or adjusted $R^2$ is above 0.3 in all models) and results are consistent when using different estimation methods. As can be seen, the coefficients' sign, size and significance are relatively stable across the probit, logit and linear models.

The coefficient of strength of ties, our main explanatory variable, is positive and significant when explaining the probability of choosing the bi-directional channel while it is negative and significant when explaining the probability of selecting the service channel. In other words, the stronger the personal relation the most likely interactions will be performed through the bi-directional channel. On the contrary, when personal relationships are weaker, researchers and firms choose to interact through types of interaction that occur through the service channel.

Therefore, we can validate hypotheses H.1.1, that the existence of strong personal ties is positively associated to the probability of choosing the bi-directional channel and H.1.2., that the existence of weak personal ties is positively associated to the probability of choosing the services channel.

Regarding the other explanatory variables, the team size shows a negative effect on the probability of using the bi-directional channel. Large research teams do normally have an important training goal for the (many) PhD students that belong to those teams.[11] So one

[11] In research teams of more than ten members, there is in average one Ph.D. student per full-time researcher, while in research teams of less than ten members, the proportion is one Ph.D. student every two full-time researchers.

**Table 4** Probability models on the channel selection

| Variables | Probit (marginal effects) | | Logit (marginal effects) | | Linear | |
|---|---|---|---|---|---|---|
| | Channels | | | | | |
| | Bi-directional | Service | Bi-directional | Service | Bi-directional | Service |
| Strengh_ ties | 0.143** | −0.190** | 0.124* | −0.187** | 0.146*** | −0.141** |
| | [0.0576] | [0.0857] | [0.0634] | [0.088] | [0.0504] | [0.0574] |
| Fin_motiv | −0.0769 | 0.132 | −0.07 | 0.139 | −0.121 | 0.128 |
| | [0.0924] | [0.0988] | [0.0797] | [0.0935] | [0.0733] | [0.0806] |
| Know_motiv | 0.144 | −0.0239 | 0.12 | −0.015 | 0.173** | −0.00635 |
| | [0.129] | [0.119] | [0.157] | [0.1391] | [0.0766] | [0.0862] |
| Prize | 0.256** | −0.316** | 0.236** | −0.299* | 0.323** | −0.337** |
| | [0.102] | [0.142] | [0.1104] | [0.165] | [0.124] | [0.140] |
| Size_team | −0.0351** | 0.0276* | −0.032** | 0.028 | −0.0281*** | 0.0248** |
| | [0.0148] | [0.0148] | [0.0158] | [0.01473] | [0.00867] | [0.00972] |
| Init_res | 0.0106 | −0.187*** | 0.006 | −0.191** | 0.00387 | −0.147*** |
| | [0.0473] | [0.0722] | [0.053] | [0.0838] | [0.0403] | [0.0478] |
| Agronomy | −0.0125 | −0.212 | 0.007 | −0.238 | 0.0065 | −0.172 |
| | [0.125] | [0.177] | [0.1316] | [0.1943] | [0.103] | [0.137] |
| ICT & Physics | −0.177*** | 0.286*** | −0.156*** | 0.269*** | −0.317 | 0.475* |
| | [0.0624] | [0.0805] | [0.0628] | [0.0898] | [0.256] | [0.254] |
| Veterinary | −0.12 | 0.171 | −0.103 | 0.139 | −0.0709 | 0.107 |
| | [0.114] | [0.157] | [0.1255] | [0.1731] | [0.132] | [0.147] |
| Constant | | | | | 0.381 | 0.986*** |
| | | | | | [0.225] | [0.229] |
| Observations | 105 | 105 | 105 | 105 | 105 | 105 |
| $R^2$ or Adjusted $R^2$ | 0.324 | 0.374 | 0.321 | 0.374 | 0.32 | 0.407 |
| N_clust | 29 | 29 | 29 | 29 | 29 | 29 |

Robust standard errors in brackets. Base category for discipline: Engineering

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

possible explanation for this finding could be that larger teams are busier in training human resources and do not have enough time to embark on long-term, time-consuming interactions with the private sector, such as is the case with bi-directional linkages. However, as they normally have a bigger reputation and larger infrastructure resources than smaller teams, they may be sought by private partners as technology service providers. We actually found that the effect of team size on interacting through the service channel is positive. There are also differences according to researcher field. Researchers from exact sciences are less likely than researchers from engineering (our base category) to choose the bi-directional channel and are most likely to choose the service channel. This result is mainly explained by the fact that ICT researchers do not use the bi-directional channel.[12]

[12] Only 17% of ICT interactions are carried out in the bi-directional channel, while 66% of physics interactions use that channel.

Another set of very interesting findings are those related to the researcher's profile and motivations. In general, most prestigious researchers, such as those who have won prizes, are more likely to interact through the bi-directional channel and less likely to choose the service one. Similarly, when the motivations to interact are related to knowledge goals, researchers choose the bi-directional channel and they are less likely to choose the service channel. Moreover, when it is the researchers' initiative to interact (rather than firms') they are less likely to do so through the service channel.

### 6.3 Analysis 3: testing hypotheses that relate channels of interactions and benefits

This analysis was oriented to test the second sets of hypotheses that posit that while the bi-directional channel drives primarily knowledge benefits, the service channel mainly drives financial benefits. IV 2SLS and 3SLS simultaneous equation modelling were used to control for the endogeneity of channels of interactions, since it could be argued that researchers take into consideration the expected benefits when deciding how to interact with firms.

Results for Eq. (2) are presented in Table 5.[13] The use of the bi-directional channel had a significant and positive effect on knowledge benefits and a significant and negative effect on financial benefits. This means that using the bi-directional channel is positively associated to the probability of obtaining knowledge benefits, which supports hypothesis H.2.1. Using this channel is also negatively associated to the probability of receiving financial benefits. This may just mean that bi-directional interactions are not financially rewarding to the research teams.

We also found that using the service channel is positively associated to the probability of obtaining financial benefits, as was expected by our conceptual framework. Thus, our findings also support hypothesis H.2.2.

These results are consistent for both model specifications. Other consistent results are the role played by the age of the relationship, which has a positive effect on the probability of obtaining knowledge benefits. The age of ties is an indicator used in the literature to account for the strength of ties (see Marsden and Campbell 1984), and therefore we could interpret this result as being consistent with the above mentioned literature that claims that stronger ties drive better academic performance (Villanueva-Felez et al. 2013; Balconi and Laboranti 2006).

Finally, one unexpected result is the negative effect we found between strength of ties and knowledge benefits, when Eq. (2) is estimated simultaneously with Eq. (1) using 3SLS. We showed the strength of ties is positively associated to the probability of choosing the bi-directional channel of interactions (Table 4) which in turn is positively associated to the probability of obtaining knowledge benefits (Table 5). However, once we controlled for the use of specific channels and the age of the relationship, the effect of the strength of ties is negatively associated to the probability of obtaining knowledge benefits (this result is not for 2SLS IV regression).

This result may highlight the importance of analysing the *channel* as a key mediating factor in the interaction between firms and researchers. The result could be interpreted as the opportunity costs for researchers (in terms of knowledge outputs) to establish strong

[13] In "Appendix 2" we presented the results of the first stage for IV 2SLS estimation and also the estimated coefficients for Eq. (1) for 3SLS estimation. These results are very similar to those presented in Table 4.

**Table 5** The determinants of benefits of interaction

| Variables | IV 2SLS | | | | Simultaneous Equation 3SLS: Equation 2 | | | |
|---|---|---|---|---|---|---|---|---|
| | Benefits | | | | Benefits | | | |
| | Knowledge | Knowledge | Financial | Financial | Knowledge | Knowledge | Financial | Financial |
| $Ch_{bi}$ | 0.449* | | −1.186** | | 0.434** | | −1.189*** | |
| | [0.256] | | [0.464] | | [0.178] | | [0.301] | |
| $Ch_{ser}$ | | −0.149 | | 0.619* | | −0.15 | | 0.637*** |
| | | [0.135] | | [0.367] | | [0.110] | | [0.178] |
| Strengh_ties | −0.0986 | −0.0562 | 0.102 | 0.0207 | −0.0958** | −0.0564* | 0.103 | 0.0242 |
| | [0.0674] | [0.0576] | [0.125] | [0.104] | [0.0420] | [0.0340] | [0.0713] | [0.0539] |
| Link_age | 0.0137* | 0.00945** | 0.00181 | 0.0109 | 0.0113** | 0.00962** | 0.00122 | 0.00708 |
| | [0.00704] | [0.00464] | [0.0117] | [0.00814] | [0.00498] | [0.00468] | [0.00685] | [0.00676] |
| Constant | 0.659*** | 0.907*** | 0.999*** | 0.211 | 0.684*** | 0.906*** | 1.006*** | 0.232* |
| | [0.152] | [0.102] | [0.167] | [0.325] | [0.0810] | [0.0827] | [0.128] | [0.132] |
| Observations | 98 | 98 | 97 | 97 | 98 | 98 | 97 | 97 |

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

personal (probably time-consuming) relationships with firms when it does not take place specifically through the bi-directional channel.

## 7 Discussion and conclusions

This paper lies at the intersection between social network literature and PROs-industry literature. Particularly, we analyse the extent to which the strength of ties explains the selection of different channels of interaction and their associated benefits for researchers. We believe the contribution of this paper is both theoretical and empirical: theoretical because as far as we are aware there are no papers analysing the association between strength of ties and channel selection, while there are very few that discuss the role played by the strength of ties on PROs-industry interactions altogether; and empirical because most of the relevant literature has been produced in the context of developed countries, whose S&T systems have features and challenges radically different to those of developing countries. This paper contributes to balancing the literature by analysing the case of Argentina, a middle-income country.

In recent years, S&T policies in Argentina put a strong emphasis on creating knowledge networks. Several support PROs-industry schemes have been developed under the premise that these are key instruments for strengthening innovation, both by increasing knowledge exchange among different actors in the NIS and by stimulating further R&D investments in the private sector. More interaction can lead to more and better research projects while enhancing the use of scientific knowledge by the private sector.

However, private investments in innovation have remained very low by international standards. Furthermore, the NIS is fairly poorly articulated; there are wide geographical asymmetries and although PROs-industry interactions have increased, they are still fairly local, short-term and rare for the vast proportion of private actors. Therefore, S&T policy faces great challenges. We need to be creative in designing tools that encourage better use of knowledge capabilities currently present in PROs.

We believe this study may contribute to that aim by means of recognizing the social nature of interaction processes. This study provides a new dimension for analysing PROs-industry linkages. Many previous studies have advanced in identifying different modes of interactions between academia and industry. Some others have advanced by means of assessing benefits and risks associated to different channels. However, few studies have adopted a *social network perspective* to analyze the relation between the characteristics of social ties and actors' decisions regarding channels of PROs-industry interactions.

Our contribution, we believe, is to add the concept of strength of tie as a dimension to explain the selection of different channels of interactions which in turn drive different type of benefits of interaction. We used Arza's (2010) taxonomy for channels and benefits of interaction. We constructed variables to account for the use of the bi-directional (i.e. long-term reciprocal knowledge flows) and the service channel (i.e. short-term unidirectional service provision from PROs to firm) and for obtaining financial and intellectual benefits through PROs-industry interaction.

We collected case-study evidence using a semi-structured questionnaire in face-to-face interviews with 57% of principal researchers of a medium-sized Argentinian university in 2013. We estimated different econometric models using individual ties as the unit of analysis. Following Granovetter (1973) we defined the strength of tie as a combination of friendship, trustworthiness, reciprocity of knowledge exchange, and frequency of interaction.

The results suggested that the strength of tie is associated to the probability of choosing different channels of interaction. Indeed we found that the strong ties between researchers and firms are associated with a higher probability of selecting the bi-directional channel, while weak ties are associated with a higher probability of selecting the service channel. We interpret this result as the importance that personal relationships (based on trust, friendship and reciprocity) have on deciding on whether to commit time, knowledge and resources to long-term, demanding and risky interactions.

We then related interaction channels with interaction benefits, although our data was not optimal for the latter. We did not have information on benefits at a tie level; rather we had information regarding researchers' opinions on linkages with the private sector in general. We used that information to build binary variables on financial benefits and intellectual benefits (contributions to teaching activities, scientific reputation or project relevance) at researcher level.

We used those variables as dependent variables to assess the relative effectiveness of different channels of interactions, as had been done previously in other studies (Arza and Vazquez 2010, 2012; Aslesen and Freel 2012; Chaves et al. 2012; De Fuentes and Dutrénit 2012; Kruss 2012; Rivera-Huerta et al. 2011; Treibich et al. 2013). Consistently with the received literature we found that using the bi-directional channel increased knowledge benefits of interactions while using the services channel increased financial benefits.

Our results have major implications for public policies, managers involved in LO and other actors interested in promoting PROs-industry interactions. It brings to the fore the need to conceptualize PROs-industry collaborations more holistically, which includes not only technical and legal dimensions, but also the relational, social and historic nature of these processes. Operatively, this implies somehow replacing the rationale and technical perspective that currently characterizes the promotion of linkages, with a more flexible, unstructured and fluid approach that invites people to interact and participate. Without neglecting the importance of developing concrete incentive schemes for both firms and researchers promoting interaction, we believe a broader understanding of the interaction process as a social process is also needed. A series of concrete actions designed to open up PROs activities to the community (including local entrepreneurs) such as science community workshops, science days, fairs, and other activities involving training, socialization and discussions could help. Moreover, the strength of tie can also be enhanced in geographically-distant relationships by using collaborative online platforms.

Finally, we should mention that this study has a number of limitations, which create new opportunities for further research on the subject. One of these limitations is that the strength of ties is measured using information just on one side of the interaction (researchers), without taking into account the counterpart (firms)'s vision. This creates limitations to apply statistical models for social networks that could better support statistical inference in network formation. For this reason we have been careful not to interpret causal effects from our results. Another data constraint is that we did not have information of benefits associated to each interaction but the overall experience of researchers interacting with several firms. Finally, since our data come from one single medium-size university, we only had the chance to analyse the effect of strength of ties on those channels more prominently used by researchers: i.e. the bi-directional and service channel. We could not analyse how the strength of ties affects the selection of the traditional channel and the commercial channel due to insufficient observations. The lack of information on the traditional channel is very much related to the fact that we only have data informed by researchers, who may not be aware of the extent to which firms use the exchange of research outputs through the traditional channel (e.g. publications, trained graduates, etc.). However, the lack of information on the use of the commercial channel somehow reflects the marginal importance of patents, licences, and spin-offs in developing countries.

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## Appendix 1

See Table 6.

**Table 6** Description of variables

| Concept | Variable name | Type of data | Definition |
|---|---|---|---|
| Traditional channel | $Ch_{trad}$ | Binary | This is defined by knowledge flows derived from traditional functions of the academic/research institution. We include here: publications, informal contacts, conferences and exhibitions and recently-hired graduates |
| Service channel | $Ch_{serv}$ | Binary | Interactions that could be associated with the provision of scientific and technological services in exchange for money, where knowledge flows mainly from PROs to firms. We include here: testing, trials, technical assistance, training staff, consultancy and personnel exchange |
| Bi-directional channel | $Ch_{bi}$ | Binary | In this case the knowledge flow is bi-directional and the potential for joint learning is high. We include here: long-term research contracts, participation in public–private research networks, research and development projects and scientific park |
| Commercial channel | $Ch_{com}$ | Binary | This is defined as the commercialization of research results. We include here: spin-offs, incubators, patents and licenses |
| Frequency of contact of links | Link_freq | Ordinal | This measures the frequency of communication between researchers and businesses. A Likert scale was used with the following values: at least once a week, at least once a month, at least once every three months, at least once every six months, at least once a year |
| Level of friendship of ties | Link_friend | Ordinal | This measures the degree of personal closeness and friendship between the researcher and contact person within the company. The researcher was requested to define how much they agreed with the following sentence: "The contact person in the company is a friend of mine." A Likert scale was used with the following values: strongly agree, agree, neither agree nor disagree, disagree, strongly disagree |

**Table 6** continued

| Concept | Variable name | Type of data | Definition |
|---|---|---|---|
| Trust level in a link | Link_trust | Ordinal | This measures the degree of trust the researcher has in the company with which he/she is linked. To measure this, we asked the researcher to establish how much they agreed with this statement: "The contact person in the company is reliable." A Likert scale was used with the following values: strongly agree, agree, neither agree nor disagree, disagree, strongly disagree |
| Level of reciprocity of links | Link_recip | Ordinal | Reciprocity is associated with the direction of the flow of information and knowledge between the parties that established a link. Reciprocity is considered to exist when the connection involves reciprocal flow of information and knowledge between the parties. To measure this, we asked the researcher to how much they agreed with this statement: "The exchange of information and advice is reciprocal." A Likert scale was used with the following values: strongly agree, agree, neither agree nor disagree, disagree, strongly disagree |
| Strength of ties | Strength_ties | Continuous | Inspired by Granovetter's definition, we approximated the concept of strength of tie as a linear combination of friendship, trustworthiness, reciprocity of knowledge exchange, and frequency of interaction. Using factor analysis we constructed a synthetic indicator that accounted for the common variability of those four dimensions |
| Team Quality | Prize | Binary | Obtaining awards/external recognition. This was used as a proxy for measuring the quality of the research team. This variable takes the value 1 if the research team has received awards and 0 if it has not received any |
| Size of the group | Size_team | Count | Total number of members of the research group (including researchers, scholars and support staff) |
| School | Agronomy | Binary | This variable takes value 1 if academics conduct research in the School of Agronomy studies |
| | Engineering | Binary | This variable takes value 1 if academics conduct research in the School of Engineering |
| | ICT & Physics | Binary | This variable takes value 1 if academics conduct research in the School of Exact Sciences, but only Physics and ICT researchers were interviewed |
| | Veterinary | Binary | This variable takes value 1 if academics conduct research in the School of Veterinary studies |
| Knowledge motivations | Know_motiv | Continuous | Motivation for linking to the private sector that is somehow related to researchers' interest in improving the research or teaching quality. We include: to develop research projects that can only be done in collaboration with firms; to acquire new skills or abilities by linking; to get new research ideas; to access knowledge owned by the private sector (patents and licenses); and to test and to disseminate the results of research. In our questionnaire, researchers had to evaluate the importance of each of these motivations using a Likert scale (not important, slightly important, somewhat important, important, very important). Our variable is the standardized average of original responses |

**Table 6** continued

| Concept | Variable name | Type of data | Definition |
|---|---|---|---|
| Financial motivations | Fin_motiv | Continuous | Motivation for linking to the private sector that is somehow related to researchers' interest in diversifying financial sources and increasing funding. In this category we include: to optimize the time and/or costs of research projects; to get resources to fund research or purchase installations or equipment; to build reputation to facilitate access to resources; to access specialized technological equipment or technologies from the private sector; and to ensure the presence of representatives from companies in academic advisory bodies. In our questionnaire, researchers had to value the importance of each of these motivations using a Likert scale (not important, slightly important, somewhat important, important, and very important). Our variable is the standardized average of original responses |
| Initiative to begin the link | Init_res | Ordinal | This measures how often the researcher initiated the connection with the private firm. A Likert scale was used with the following values: never, rarely, sometimes, often, always |
| Duration of interaction | link_age | Continuous | Number of years that the research group has been linked to the firm |
| Knowledge benefit | Knowledge Benefit | Binary | This takes value 1 when linking to the private sectors improved teaching activities, scientific reputation of research teams or the relevance of project orientation |
| Financial benefit | Financial benefit | Binary | This takes value 1 when linking to the private sectors improved the financial situation of research projects |

## Appendix 2

See Table 7.

**Table 7** Probability estimates of choosing bi-directional and service channel when estimating the benefits of interaction

| Variables | When estimating Knowledge Benefits | | | | When estimating Financial Benefits | | | |
|---|---|---|---|---|---|---|---|---|
| | IV 2SLS: Instrumentation | | 3SLS: Eq. 1 | | IV 2SLS: Instrumentation | | 3SLS: Eq. 1 | |
| | Channels | | | | Channels | | | |
| | Bi-directional | Service | Bi-directional | Service | Bi-directional | Service | Bi-directional | Service |
| Strengh_ ties | 0.14* | −0.13** | 0.130*** | −0.133*** | 0.139** | −0.136** | 0.107*** | −0.113*** |
| Fin_motiv | −0.112 | 0.142* | −0.0791 | 0.130* | −0.112 | 0.142* | −0.189*** | 0.205*** |
| Know_motiv | 0.187** | −0.001 | 0.205*** | −0.0159 | 0.183** | −0.016 | 0.0963 | −0.0325 |
| Prize | 0.281** | −0.340** | 0.409*** | −0.350*** | 0.282** | −0.337** | 0.388*** | −0.432*** |
| Size_team | −0.027*** | 0.026*** | −0.0226*** | 0.0251*** | −0.027*** | 0.026*** | −0.0361*** | 0.0374*** |
| Init_res | 0.018 | −0.142*** | 0.00889 | −0.146*** | 0.019 | −0.14** | −0.0477 | −0.0727* |
| Agronomy | 0.063 | −0.264 | 0.0623 | −0.263** | 0.064 | −0.261 | −0.0628 | −0.128 |
| ICT & Physics | −0.255 | 0.499** | −0.14 | 0.446** | −0.249 | 0.52** | −0.351** | 0.542*** |
| Veterinary | 0.004 | 0.115 | 0.0843 | 0.0692 | 0.001 | 0.104 | −0.197** | 0.190* |
| Link_age | −0.005 | −0.003 | | | −0.005 | −0.002 | | |
| Constant | 0.362 | 0.98*** | 0.178 | 1.007*** | 0.36 | 0.97*** | 0.659*** | 0.633*** |

Base category for discipline: Engineering

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

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