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THE STRENGTH OF SOCIAL TIES IN THE LITERATURE OF UNIVERSITY-INDUSTRY LINKAGES: REVIEW AND RESEARCH AGENDA

MARIELA CARATTOLI

Universidad Nacional del Centro de la Provincia de Buenos Aires (UNICEN), Centro de Estudios en Administración (CEA), Argentina
marielacarattoli@yahoo.com.ar; maricarattoli@gmail.com

SUMMARY

Even though the assessment of the processes underlying Public Research Organizations and Industry (PRO-I) linkages suggested that interpersonal relationships are crucial for knowledge transfer and for the establishment of successful cooperative activities, only few studies have adopted a social network perspective to analyse the link between the characteristics of social ties and specific aspects of PRO-I interactions. Based on this gap, the aim of this article is to understand more deeply the relationship between one key characteristics of social ties - the strength of ties - and the knowledge transfer processes in PRO-I linkages context. In order to achieve this, a detailed analysis of articles published between 1996 and 2016 in academic journals in the area of PRO–I relations was performed. The analysis suggests that adopting a perspective that takes into account the social, relational and historical nature of linking processes is essential to develop more effective policies that improve the results of PRO-I linkages. This is particularly relevant in the context of Latin America, where informal networks are widely expanded, and where the general perception among PROs and industry actors is that there is a mismatch in their capabilities, motivations, and expectations in forming knowledge linkages, which leads to wonder if the relationship is worthwhile.

Keywords: strength of ties; university-industry linkages; literature review; social ties

1 INTRODUCTION

In the last decade, the research on PRO-I linkages has received great attention (Perkmann et al, 2012; Teixeira and Mota 2012; Bekkers and Freitas 2008), due to both are key actors in the production and diffusion of new and value knowledge. The relationships they establish in the framework of knowledge networks is of great importance for the good performance of the National Innovation System (NIS) (Lundval 1992; Etzkowitz 1990; Etzkowitz and Leydesdorff 2000) and for regional development (Giuliani and Arza 2009; Salter and Martin 2001).

In fact, PRO-I literature has found that in the context of a knowledge network, universities can expand industry's capacity to solve specific and complex problems, increase productivity and offer new insight for innovation processes. 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. On the other hand, the

benefits may also reach 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 (Rosenberg 1992, Arza 2010, Dutrenit et al. 2011).

Even though the assessment of the processes underlying PRO–I relationships suggested that interpersonal relationships are crucial for the establishment of successful cooperative activities, only few studies have adopted a social network perspective to analyse the link between the characteristics of social ties and specific aspects of PRO-I interactions (Phineiro et al, 2015). In particular, the literature suggest that strength of ties is an important variable that affect knowledge transfer process, because usually this has a predictive capacity about the content and exchanges that can potentially occur within a particular relationship (Granovetter 1973; Wellman 1982; Lin et al. 1981). However, little is know regarding their relevance in the knowledge transfer processes in the PRO-I context.

Based on this gap, the aim of this article is to understand the relationship between one key characteristic of links - the strength of ties- and the knowledge transfer processes in PRO-I linkages context, by carrying out a systematic review of the literature that addresses this topics. Adopting the theoretical perspective of social networks, to understand the PRO-I linkages, could be essential to develop more effective policies that improve the results of linkages. This is particularly relevant in the context of Latin America, where the general perception among PROs and industry actors is that there is a mismatch in their capabilities, motivations, and expectations in forming knowledge linkages (Dutrénit et al. 2010; Jurado et al. 2011), which leads to doubt if the relationship is worthwhile.

In order to achieve this objective, a detailed analysis of all the empirical articles published in the last 20 years in academic journals in the area of PRO-I linkages, was performed.

The rest of article is organized as follows. Section 2 details the methodological considerations underlying the study. Section 3 presents the discussion, which is structured around three axes: a general review of the literature on PRO-I linkage, an exposition of the importance of the concept of strength of tie in the framework of PRO-I linkages, and a review of papers that specifically analyze the relationship between strength of ties and knowledge transfer process within PRO-I linkages. Section 4 summarizes the main conclusions and implications of the study and identifies promising lines of future research.

2 METHODOLOGY

A systematic review of the available evidence on the impact that strength of ties has on knowledge transfer processes in the PRO-I linkages context, was performed. Such a literature review establishes the state of current knowledge in a field (Tranfield et al., 2003), synthesises empirical evidence from large numbers of studies and identifies areas of consensus and disagreement between researchers within certain areas of research. The objective was to establish what is known about the relationship between strength of ties and different aspects of PRO-I interactions. The analysis was focused on individual ties between researchers and their industrial counterpart because the decision to link is one that, in the PRO-I context, is primarily taken on an individual level. For the current article, a simplified version of the process outlined by Tranfield et al. (2003) was performed. First, all the relevant research published on this topic from 1996 to 2016 was identified. The search was an extensive inquire into the titles and abstracts of published peer-reviewed articles,

performed using the SCOPUS database, with combinations of keywords such as "university", "business" "industry", "collaboration", "cooperation", "R&D", "linkages", "ties", "strength", "weak", "strong", "network theory", and "network analysis". The choice of SCOPUS was based on the broader range of scientific titles available when compared to Web of Science (Falagas et al., 2008). This was complemented by an intentional search for articles in the most important journals in these topics: Research Policy, Journal of Technology Transfer, and Technovation. This procedure allow to exclude possible bias towards newer studies and also to validate the search terms, given that there is little consensus on the keywords used for classifying articles in the topic analysed. The above procedure yielded 183 results.

This list was filtered according to degree of adequacy with the aim of this study. With a particular interest in studies focusing on the strength of individual ties in PRO-I linkages context, all articles that did not fulfil this criterion were removed. For example, studies at the aggregate level of country, studies that analyze the strength of ties but not in the context of PRO-I linkages or studies that focused on other aspects of the network (i.e.: size, structural characteristics, etc.) were discarded. This procedure eliminated 94 articles. The remaining one were screened applying quality and pertinence criteria to ascertain whether data had been collected in a systematic way and whether papers proposed consistent results. This procedure left a total of 36 articles.

At this stage, each remaining article was read and summarised, compiling the following information in tabular form (Pawson, 2006): article references, keywords, studies context or data used, independent and dependent variables, methodology and abstract (Appendix A) This analysis highlighted the state of the art in this topic and identified trends and research gaps to support future research.

3 DISCUSSION

Principal focus of interest in PRO-I literature

Several studies analyze the relationship between PRO-I from different focus, perspectives, methodologies and disciplines. In a review of literature about PRO-I linkages, Agrawal (2001) states that this could be divided into four categories: a) Research that focuses on the characteristics of firms involved in linking processes with PRO (size, sector, strategy, etc.); b) Research that focuses on the university characteristics involved in linking processes with firms (licensing strategies, incentives for professors to able to patent, intellectual property policies, etc.; c) Research that considers the spatial relationship between firms and PRO; d) Research that examines the relative importance of the different channels of knowledge transfer (publications, patents, consulting, spin off, etc.). In a review of academic engagement and commercialisation, Perkmann et al. (2012) mentioned, in a stylized model, different antecedents of the academic engagement, classifying these in individual (demography, professional career, productivity, attitudes, motivation, etc.), organizational (support for technology transfer, incentives, university/department quality, leadership, etc.) and institutional (scientific discipline, regulation, public policies) levels. In the same line, in a bibliometric portrait of the evolution, scientific roots and influence of the literature on university–industry links, Texeira and Mota (2012) identified new focuses about PRO-I linkages that the literature has adopted: 1) The creation of new firms (Spin offs), with one group of studies centred on the factors that inhibit the creation and development of spin-offs and other ones focusing on success factors which instigate the creation of spin-offs. 2) Studies based on the importance and function of intermediary agents in PRO–I relations in the technology transfer

process. 3) Research discussing the implications of scientific and technological policies in the national, regional or sectoral innovation system. 4) Measuring studies that examine the results of the collaboration and the frequency, intensity and efficiency of technology transfer by universities. 5) Another group of studies, which are not clearly integrated, includes reviews of the literature, analyses of the barriers to PRO–I relationships and scientometric/bibliometric analyses. Table 1 summarizes the main focus of research in the literature of PRO-I linkages.

Table 1: The main focus of research in the literature of PRO-I linkages.

Focus	*Aim*	*Authors*
Characteristics of the firms	To analyze in which fields and sectors PRO–I relationships are most frequent. To investigate the impact of aspects such as strategy, size and capabilities on the choice of channels	Santoro & Chakrabarti (2002); Salter & Martin (2001); Cohen et al. (2002); Giuliani & Arza (2009); Fontana et al. (2006); Meyer-Kramer & Schmoch (1998); Pinheiro & Teixeira (2010)
Characteristics of university or scientists	To pays attention to individual characteristics of scientists or organizational characteristics or universities that affect knowledge transfer process.	Zucker & Darby (1996); Ramos Vielba, I., & Fernández Esquinas, M. (2009), D'Este & Patel (2007)
Motivations to the creation of PRO–I relationships	To analyze the incentive for universities to spread innovations; the importance of the historical factor in PRO–I relationships and the enterprising nature of universities	O'Shea et al. (2005); Rothaermel et al. (2007); Fernandes et al. (2010), Arza & Vázquez (2010)
Spatial proximity between universities and firms	To discuss the implications of scientific and technological policies in the national, regional or sectoral innovation system	Cantner & Graf (2006); Link et al. (2008); Decter (2009); De Fuentes, & Dutrénit (2016)
Knowledge transfer channels	To take into consideration aspects pertaining to the importance of the various means of interaction between PRO-I, such as publications, patents, consultancy and informal contacts.	Cohen et al. (2002), Meyer-Kramer & Schmoch (1998); Zucker et al. (2002); Schartinger et al. (2002); Balconi & Laboranti (2006), D`Este & Patel (2007)
***Creation of new firms* (Spin-offs)**	To analyze the factors that inhibit the creation and development of spin-offs. To identify the success factors which instigate the creation of spin-offs	Shane & Stuart (2002); Di Gregorio & Shane (2003); Lockett et al. (2003); Johansson et al. (2005); O'Shea et al. (2005)
Function of intermediary agents	To study the importance and function of Technology Transfer Offices (TTOs) in PRO–I relations.	Colyvas et al. (2002); Siegel et al. (2003); Wright et al. (2008); Lee et al. (2010)
S&T policies/ National Innovation Systems	To assess the impact of S&T policies in the national, regional or sectoral innovation system	Cantner & Graf (2006); Link et al. (2008); Decter (2009); Xiwei & Xiangdong. (2007); Etzkowitz & Leydesdorff, L. (2014)
Measuring studies	To examine the results of the collaboration and the frequency, intensity and efficiency of technology transfer by universities	Tijssen (2006); Anderson et al. (2007); Ramos-Vielba et al. (2009); Todorovic et al. (2011); Belderbos et al. (2015)
Others	To review the literature, analyse the barriers to PRO–I relationships and do scientometric/bibliometric analyses	Agrawal (2001), Perkmann et al. (2012), Texeira & Mota (2012); Ankrah & AL-Tabbaa (2015)

Source: Own elaboration based on Agrawal (2001), Perkmann et al. (2012), Texeira and Mota (2012)

Hence, in general terms, the review of literature on PRO-I linkages shows that this could be divided into two types of approaches. Firstly, there are studies, mainly descriptive in nature, aiming at discussing the characteristics of firms, universities and scientists involved in PRO-I linkages, how interactions work, the role of TTOs, the motivation for interact, the performance of spin off, 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, mainly explanatory in nature, 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).

As we see, although the literature on PRO-I linkages is rich and varied, only few papers adopt a network perspective, and less have analysed how the relational characteristics of personal ties (such as strength of ties) between researchers and firms, impact on knowledge transfer process in the context of PRO-I interactions.

The importance of the strength of ties on knowledge transfer processes

Undoubtedly, network ties are beneficial in knowledge transfer processes since the combination and exchange of knowledge is a social process that requires coordination and cooperation. In this context, the importance of the concept of strength of ties is that it 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. 1981). The question that may arise is which ties are more beneficial in the knowledge transfer process in the context of PRO-I linkages. Should PRO-I linkages be based on strong or weak ties to enhance linkages outcomes? The aim of this paper is to examine the existing literature concerning this topic (strength of ties and knowledge transfer) in the context of PRO-I linkages.

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 on 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 hypothesis 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; Reagan 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 to a particular interest area for the individuals involved (Rowley et al. 2000; Uzzi 1996; 1997). These ties generate shared understandings, confidence and a common language over time (McFadyen and Canella 2004; Kogut and Zander 1996; Nooteboom et al. 2007). Strong ties are characterized by interpersonal relationships based on trust and frequent interaction, which facilitate coordination and promote the sharing of exclusive resources/knowledge among social actors in the network (Szulanski 1996; Uzzi 1996; Krackhardt 1992). They therefore also restrict opportunistic behaviour (McFadyen and Cannella 2005; Coleman 1990; Uzzi 1997), which is important in exchanging highly valuable (either symbolic or monetary) knowledge (Bouty 2000).

In short, according to Weak Ties Theory, distant and infrequent ties are proper in diffusing existent and largely codified knowledge since they provide novel and diverse information from disconnected actors. In contrast, strong ties tend to be systematic and frequent links connecting actors that trust each other and have a relationship built on reciprocity. Strong Ties Theory state that frequent and long-lasting relationships are more conducive to exchange tacit and complex knowledge, since they include trust, reciprocity and willingness to share the resources.

Strength of ties in the literature of PRO-I linkages

Specifically in the context of PRO-I linkages, Perkmann and Walsh (2007) identify a gap in research and call for research to integrate the theory of weak / strong ties in the research agenda on PRO-I interactions. As a result of these calls, the present study review the literature in order to shed new light on how PRO-I collaboration processes benefit from weak and strong ties. Very few studies that combine the social network literature about strength of ties and the PRO-I linkages literature was found. Table 2, in the appendix, summarizes all these papers.

As can be seen, the lion's share of these mostly uses the *context* of PRO-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, Thune (2007) indicates that formation of ties and interaction in collaborative relationships require familiarity, trust, common understanding and language, and a long-term commitment to the collaboration. Similarly, Amara et al (2013) mention that engagement in paid consulting for companies and government agencies is positively associated with strong ties. Fritsch and Kauffeld-Monz (2008) argued that strong ties are more favourable for knowledge exchanges in the context of regional innovation networks where universities and firms interact. On the other hand, at the individual level, Bae and Koo (2008) find that dense networks comprised of weak ties afford more valuable knowledge if information loss is trivial and the cost of initiating ties is larger than the cost of transfer, but that the value of density declines rapidly as information loss increases. At the organizational level, in contrast, sparse networks with strong ties

appear optimal for knowledge transfer via social relations. Liu et al. (2009) show that strong ties, which have high interaction frequency, close intimacy, greater reciprocity, can facilitate knowledge transfer among team members. 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. In this sense, Bouty, I. (2000) also found that strategic resources can only be exchanged under conditions of acquaintance and mutual trust. Villanueva-Felez and Mollas Gallart (2011) claimed that the strength of ties is vital for exchanging new information. Similarly, Johansson et al (2008) argued that strong ties are very useful for transferring complex knowledge between spin-offs and universities. Finally, Bergenholtz & Bjerregaard (2014) argue that the significance of weak and strong ties is relative to varying institutional conditions.

Only few studies that inquire into the relation between strength of ties and specific aspects of interactions, such as academic performance, risks of knowledge misappropriation, conflicts that stem from differences in the socio-cultural background, was found.

The role of the strength of ties on academic performance has been studied by Villanueva-Felez et al. (2013) who found that researchers that are part of an integrated network with a mix of strong and weak ties achieve better research results. Over embedded networks are related to with lower academic output. The same can be said of researchers with completely homogeneous networks: they display the poorest academic output results. Nodal heterogeneity is positively and significantly related with research output. McFadyen et al. (2009) suggests that strength of ties average interacts with density to affect knowledge creation such that researchers who maintain mostly strong ties with research collaborators who themselves comprise a sparse network have the highest levels of new knowledge creation. Petruzzelli et al. (2010) reveal that universities' knowledge mobility is positively affected by the establishment of strong inter-organizational ties. Wang (2016) found an inverted U-shaped relationship between strength of ties average and citation impact, because an increase in ties strength on the one hand facilitates the collaborative knowledge creation process and on the other hand decreases cognitive diversity. In addition, when the average tie strength is high, a more skewed network performs better because it still has a “healthy” mixture of weak and strong ties and a balance between exploration and exploitation. Furthermore, the ties strength skewness moderates the effect of network average ties strength: both the initial positive effect and the later negative effect of an increase in ties strength are smaller in a more skewed network than in a less skewed one. Additionally, Balconi and Laboranti (2006) argued that stronger connections are associated with high scientific performance, while Sánchez-Navas and Ferràs-Hernández (2015) found that trust and commitment are positively related to R&D alliance performance. Chen et al (2008) revealed that social interaction and network ties had significant and positive impacts on creativity of R&D project teams but mutual trust and shared goals did not. Rost (2011) demonstrates that, in the presence of strong ties, weak network architectures (structural holes or a peripheral network position) leverage the strength of strong ties in the creation of innovation. Filieri et al. (2014) show that for knowledge to be exploited, the network configuration has to evolve from a sparse network (small in size and characterized by weak ties across multiple organizational networks) to a large and cohesive network configuration characterized by high levels of commitment, trust, fine-grained information exchange, and joint problem solving.

Other studies focused on conflicts of PRO-industry interactions and argued that the strength of ties could contribute to overcoming them. Bruneel et al. (2010) concluded that trust helped 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 PRO-industry interactions had commercial value, partners are likely to be reluctant to exchange strategic resources unless the relationship is built on strong ties. Soetanto & Van Geenhuizen (2015) found that strength of ties have a positive relationship with the spin-offs ability to attract funding. Steinmo (2014) explores how the development of cognitive and social capital can mitigate the challenges between firms and PROs in research alliances and facilitate effective collaboration over time. Common goals and understanding the aim of the collaboration as well as creation of personal relations between firms and PROs mitigates collaboration challenges and thereby lead to better collaboration performance over time. Finally, McFadyen and Cannella (2005) also claimed that opportunistic behaviour is minimised if closeness and trust characterize the relation between partners.

4 IMPLICATIONS AND FUTURE LINE OF RESEARCH

Research on PRO-I linkages shows that inter-organisational relationships are often based on informal social relationships between individuals (Owen-Smith and Powell 2003; Zucker and Darby 1996). Even though the assessment of the processes underlying PRO-I linkages suggested that interpersonal relationships are crucial for knowledge transfer processes, only few studies have adopted a social network perspective to analyse the link between the characteristics of social ties and specific aspects of PRO-I interactions. Following Perkmann and Walsh (2007) who called to researchers to integrate the theory of weak / strong ties in the research agenda on PRO-I interactions, this study reviews the PRO-I literature in order to shed new light on how PRO-I collaboration processes benefit from weak and strong ties.

Most of the literature presents an incentive-based explanation for the processes of formation and development of OPI-I links, where the R&D needs of knowledge-intensive firms and the funding needs of universities create interdependence which motivates both parties to interact (Thune, 2007). Without disclaim the relevance of approaches that consider resource dependence as a fundamental precondition for the PRO-I linkages, we agree with Thune (2006) that these approaches are insufficient to develop a comprehensive understanding of the processes that give rise to effective PRO-I articulations. In addition to the incentives, other factors are also relevant to understand these processes, especially those factors that related to the nature and characteristics of personal relations that established between researchers and firms in the context of a specific linkages. However a few studies that combine literature about the nature of ties (i.e. strength of ties) and PRO-I linkages were found. Most of them have a descriptive nature and use the context of PRO-industry interactions to analyse the role of strength of ties on knowledge outcomes as the social network literature has done for different contexts. In general, the innovation literature, found that trust and strong ties are of great importance for knowledge transfer processes, especially in the context of PRO-I linkages. This contradicts Granovetter's hypothesis about the strength of weak ties. According to the weak tie theory originally advanced by Granovetter (1973), distant and infrequent relationships (i.e., weak ties) are more efficient for knowledge transfer than the strong ties, because they provide access to novel and non redundance information. The diferences between the innovation literature and the social networks literature on the effect of strength of ties on knowledge transfer processes could be partially explained by differences in approach. While the research on social networks tends to focus on the problem of search or acces to information, the literature on innovation tends to focus on learning and knowledge creation process (Hansen, 1999).

The transfer of knowledge in the context of PRO-I interactions, however, involves a dual problem of search/access and transfer/creation of knowledge, depending on the motivations that the parties have when establishing their links. Then, the question about to whether strong ties or weak ties lead to a more efficient exchange of knowledge is higly relevant. In this sense, the results of the literature review are in many cases contradictory, evidencing that the effects of strength of ties on the results of transfer processes depends on the type of knowledge being exchanged and (tacit vs. codified, simple vs. complex, new vs. existing, etc.) and the motivations that give rise to the linkage (search / access vs. assimilation / creation) (Filieri and Alguezaui, 2014).

In this sense, more research is needed in reference to the impact of the strength of individual ties (researcher/company) on the results of PRO-I linkages, that take into account different contingency factors such as: the type of knowledge that is exchanged (tacit or codified, new or existing, dependent or independent), links motivation (search/access or assimilation/creation of knowledge), channel of knowledge transfer (services, patents, spin off, etc.) and the institutional context where the link is developed (sector, country, size of participants, etc.). Progress on these issues is especially important in the context of Latin America, with weakly articulated institutional frameworks and unstable contexts, where informal networks are widely expanded and underlying social processes, and interpersonal relationships that take place within concrete articulations may in some way supplant institutional failures to support the PRO-I linkages.

Our results could have major implications for public policies, managers involved in LO and other actors interested in promoting PRO-I interactions. It brings to the fore the need to conceptualize PRO-industry collaborations more holistically, which includes not only a rational and logical perspective, but also the relational, social and historic nature of these processes. Operatively, this implies somehow complement the perspective of the resources dependence, 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 PRO 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

On other hand, only few studies that inquire into the relation between strength of ties and specific aspects of interactions were found. This opens new and interesting research agendas, from the cross-fertilization of two rich fields of research: network theory and studies on PRO-I linkages. In particular, further research is needed to analyze the impact of strength of ties on specific aspects of PRO-I interactions, such as: the channels of transfer through which ties are implemented, the benefits and risks of linking and the academic performance.

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APPENDIX

Table 2: Overview of the articles included in the review

Citation	Data/Context	Dependent Variable	Independent variables	Methodology Technique
Amara, N., Landry, R., & Halilem, N. (2013) Faculty consulting in Natural Sciences and Engineering: between formal and informal knowledge transfer. Higher Education, 65(3) 59-384.	2590 Canadian researchers in engineering and natural sciences	Patterns of consulting	Industry funding Research laboratories size Research universities size Technical validation of knowledge Protection of IP Strength of ties	Quantitative Regression models
Bae, J., & Koo, J. (2008). Information loss, knowledge transfer cost and the value of social relations. Strategic Organization, 6(3), 227-258.	4 type of relations: sparse network with weak ties, sparse network with strong ties, dense network with weak ties, dense network with strong ties	Value of transferred knowledge	Strength of ties Structure of social relations Information loss Transfer cost	Agent-based simulation and experiment
Balconi, M. , Laboranti, A. (2006) University-industry interactions in applied research: The case of microelectronics Research Policy, 35 (10), 1616-1630	Italian system of research and innovation in electronics.	Scientific performance.	Researchers spheres Strength of ties	Social Network Analysis (SNA)
Bergenholtz, C., & Bjerregaard, T. (2014). How institutional conditions impact university–industry search strategies and networks. Technology Analysis & Strategic Management, 26(3), 253-266.	Unisense, a high-tech small firm	UI search and collaboration processes	Different industrial sectors Different search strategies Strength of ties	Case study
Bond, E., Houston, M. & Tang, Y. (2008). Establishing a high-technology knowledge transfer network: The practical and symbolic roles of identification. Industrial Marketing Management, 37(6), 641-652.	15 participants, including members of research and technology organizations, university researchers, and firm managers.	Key outcomes of start-up Knowledge-transfer benefits	Centrality in the network Identification with the KTN Participants' affective commitment	Conceptual model and Quantitative UCINET, 6.150 version Multiple regression analyses
Bouty, I. (2000). Interpersonal and interaction influences on informal resource exchanges between R&D researchers across organizational boundaries. Academy of Management Journal, 43(1), 50-65.	38 researchers in France in chemicals, pharmaceuticals, electronics, food, glass, cosmetics or in public research.	Resource acquisition process	Social capital Competition Acquaintance/Mutual trust Type of Partners Grounds	Grounded theory
Bruneel, J., d'Este, P., & Salter, A. (2010). Investigating the factors that diminish the barriers to university–industry	All the private, for-profit organizations with formal involvement in EPSRC	Orientation-related barriers and transaction-related	Collaboration experience Breadth of interaction Inter-organizational trust	Quantitative Fractional logit regression

collaboration. Research Policy, 39(7), 858-868.	collaborative projects	barriers to U-I collaboration		
Filieri, R., McNally, R., O'Dwyer, M., & O'Malley, L. (2014). Structural social capital evolution and knowledge transfer: Evidence from an Irish pharmaceutical network. Industrial Marketing Management, 43(3), 429-440.	7 academics and 11 industry managers of pharmaceutical companies	Content of knowledge transfer Structural elements of social capital	Network developed	Qualitative Case study
Friedkin, N. (1982). Information flow through strong and weak ties in intraorganizational social networks. Social networks, 3(4), 273-285.	Scientific work among faculty members in the biological, physical, and social sciences divisions of Columbia University and the University of Chicago	Probability of information flow	Strength of interpersonal ties	Quantitative Regression Model
Fritsch, M., y Kauffeld-Monz, M. (2010) The impact of network structure on knowledge transfer: An application of social network analysis in the context of regional innovation networks. Annals of Regional Science, 44, 21-38.	16 East German regional innovation networks that were initiated in 1999.	Extent of information and knowledge transferred and absorbed from network partners.	Characteristics of network Characteristics of actor's ego-network Positions of an actor in his ego-network Individual characteristics	Social Network Analysis
Gubbins, C., & Dooley, L. (2014). Exploring social network dynamics driving knowledge management for innovation. Journal of Management Inquiry, 23(2), 162-185.	3 university-industry knowledge networks generating new knowledge within life sciences.	Key stages of knowledge management for innovation process.	Structural, relational, and cognitive social capital components	Qualitative Case studies
Hayter, C. S. (2015). Social networks and the success of university spin-offs: toward an agenda for regional growth. Economic Development Quarterly, 29(1), 3-13.	Faculty entrepreneurs in New York State.	Success of university spin-offs	Social networks	Quantitative
Hemmert, M., Bstieler, L., & Okamuro, H. (2014). Bridging the cultural divide: Trust formation in university–industry research collaborations in the US, Japan, and South Korea. Technovation, 34(10), 605-616.	UICs in biotechnology, microelectronics and software industries in the US, Japan and Korea	Trust	Strength of ties Partner Reputation Contractual safeguards Champion behavior	Quantitative Regression analysis
Hirai, Y., Watanabe, T., & Inuzuka, A. (2013). Empirical analysis of the effect of Japanese university spinoffs' social networks on their performance. Technological Forecasting and Social Change, 80(6), 1119-1128.	1352 Japanese university spin-offs by the Ministry of Economy, Trade and Industry	University spin-offs' performance (sales volume, employment, and competitive capabilities)	Social networks Non redundancy Strength of ties	Quantitative Multiple linear regression analysis

Johansson, M., Jacob, M., & Hellström, T. (2008). The Strength of Strong Ties: University Spin-Offs and the Significance of Historical Relations. In Knowledge Matters.. Palgrave Macmillan UK. 179-202	4 companies of various sizes and activities in Sweden	Antecedents and reasons for continued relations between universities and academic spin-offs	Motivations for spin-offs Content of linkages Sustaining linkages	Qualitative Instrumental and Multiple Case studies (4)
Liu, H., Fu, Y., & Chen, Z. (2009). Effects of social network on knowledge transfer within R&D team. In International conference on information management, innovation management and industrial engineering (3), 158-162		Ease, cost, efficiency and satisfaction of knowledge transfer	Network Structure (Size; Density; Centrality; Content) Nature of interpersonal interaction (strength of ties)	Quantitative Factor analysis. GAMMA estimate
McFadyen, M., Semadeni, M., & Cannella, A. (2009). Value of strong ties to disconnected others: Examining knowledge creation in biomedicine. Organization Science, 20(3), 552-564.	University biomedical research scientists from the Community of Science expertise database and their publications and coauthors over 1989–1999.	Knowledge Creation	Strength of ties average Network density	Quantitative Negative binomial model
Petruzzelli, A., Albino, V., Carbonara, N., & Rotolo, D. (2010). Leveraging learning behavior and network structure to improve knowledge gatekeepers' performance. Journal of Knowledge Management, 14(5), 635-658.	Longitudinal study (2000-2007) of collaborative R&D relationships by 3 UK universities of joint-patents registered at the European Patent Office.	Capability to collect and diffuse knowledge	Universities learning behavior (explorative/exploitative) Network structure (weak/strong ties)	Quantitative
Pinheiro, M., Pinho, J., & Lucas, C. (2015). The outset of UI R&D relationships: the specific case of biological sciences. European Journal of Innovation Management, 18(3), 282-306.	Biological sciences community in Portugal	U–I relationships in the context of R&D cooperation networks for innovation		Qualitative
Sandberg, J., Holmström, J., Napier, N., & Levén, P. (2015). Balancing diversity in innovation networks: Trading zones in university-industry R&D collaboration. European Journal of Innovation Management, 18(1), 44-69.	4 distinct R&D collaborations involving 12 R&D centers in IT at the universities of Umeå (5), Luleå (5) or both of them (2)	Diversity in innovation processes	Types of trading zones (transformative/ performative) Strategy configuration dimensions (means of knowledge trade, tie configuration, knowledge mobility mechanisms and types of trust).	Qualitative Case study
Santoro, M., & Saparito, P. (2006). Self-interest assumption and relational trust in university-industry knowledge transfers. IEEE Transactions on Engineering Management, 53(3), 335-347.	180 small to large-sized industrial firms working with university research centers	Knowledge Transfer	Self-Interest Assumption Relational Trust	Quantitative Multiple linear regression

Soetanto, D., & Van Geenhuizen, M. (2015). Getting the right balance: University networks' influence on spin-offs' attraction of funding for innovation. Technovation, 36, 26-38.	University spin-offs from 2 technical universities: Delft University of Technology, Norwegian University of Science and Technology	Spin-offs ability to attract funding for innovation	University and non-university network density University and non-university strength of ties	Quantitative Hierarchical regression analyses
Sorenson, O., Rivkin, J. W., & Fleming, L. (2006). Complexity, networks and knowledge flow. Research policy, 35(7), 994-1017.	Prior art citations to all U.S. utility patents granted in May and June of 1990 (n = 17,264).	Interdependence of patent Complexity of the knowledge in a patent	Geographic, social and organizational proximity	Quantitative Rare events logit models
Steinmo, M. (2014). How Social Capital Mitigate Collaboration Challenges in University-Industry Research Alliances: A Longitudinal Case Study. In Proceedings of the 2014 DRUID Society Conference 1-22.	1 well-established research Alliance and 1 emerging research Alliance in Norway.	Performance of collaboration between firms and PROs	Cognitive and social capital	Quanlitative Case study
Thune T. (2007) University–industry collaboration: the network embeddedness approach *Science and Public Policy*, 34(3), 158–168	29 researchers and R&D managers in universities and firms involved in collaborative R&D projects.	Forming and carrying collaborative projects	Social capital resources	Qualitative
Villanueva Félez, Á., & Molas Gallart, J. (2011). Exchanging information through social links: The role of friendship, trust and reciprocity. INGENIO (CSIC-UPV).	866 scientists working in the field of nanotechnology	Access to novel information Access to specific information	Characteristics of the personal ties (emotional intensity, mutual confiding, reciprocal services, degree of friendship level of reciprocity degree of trust)	Quantitative Ordered logit regressions
Villanueva Félez, Á., Bekkers, R., & Molas Gallart, J. (2009). Diversity in knowledge transfer: A network theory approach.INGENIO (CSIC-UPV)	Scientists working in the field of nanotechnology	Diversity of Knowledge transfer channel	Interdisciplinarity Pervasiveness Geo distance Tie strength	Quantitative Ordered LOGIT regression analysis
Villanueva Felez, A., Benneworth, P., & Molas-Gallart, J. (2015). Resources exchange patterns with diverse institutional partners within R&D collaborative relationships: access to reputation and funding. INGENIO (CSIC-UPV)	Relationships maintained by scientists at state-funded research centers working in advanced materials at the nanoscale.	Reputation Funding and tangible assets	Tie strength	Quantitative Non- parametric statistical techniques Ordered logistic regressions
Villanueva-Felez, A., Molas-Gallart, J., & Escribá-Esteve, A. (2013). Measuring personal networks and their relationship with scientific production. Minerva, 51(4), 465-483.	64 researchers from 6 departments from the University of Valencia (Spain), related to business and management.	Research output	Degree of embeddedness Nodal heterogeneity	Quantitative Mann-Whitney U test

Wang, J. (2016). Knowledge creation in collaboration networks: Effects of tie configuration. Research Policy, 45(1), 68-80.	Bibliometric data for 1042 american scientists in biology, chemistry, computer science, earth and atmospheric sciences, electrical engineering, and physics	Knowledge creation	Egocentric Collaboration network Network size Tie strength	Quantitative Regression analysis
Díez-Vial, I., & Montoro-Sánchez, Á. (2014). Social capital as a driver of local knowledge exchange: a social network analysis. Knowledge Management Research & Practice, 12(3), 276-288.	Madrid science park in spain	Knowledge exchange	3 dimensions of social capital	Social network analysis
Chen, M., Chang, Y., & Hung, S. (2008). Social capital and creativity in R&D project teams. R&d Management, 38(1), 21-34.	54 R&D project teams in high-technology firms of Taiwan	Creativity of R&D project teams	Social capital	Quantitative Factor analysis and regression analyses
Capaldo, G., Costantino, N., Pellegrino, R., & Rippa, P. (2016). Factors affecting the diffusion and success of collaborative interactions between university and industry: The case of research services. Journal of Science and Technology Policy Management, 7(3), 273-288.	Research services experienced between 2 big Italian universities and SMEs.	Factors affecting the birth and success of interactions, as perceived by researchers and by firms		Qualitative Multiple case studies
Rost, K. (2011). The strength of strong ties in the creation of innovation. Research policy, 40(4), 588-604.	Sample of inventors from the German automotive industry limited to patent activities	Patent Citations (Backward and Forward)	Strength of ties Ego network closure Structural holes	Quantitative Negative binomial regression
Sánchez-Navas, A., & Ferràs-Hernández, X. (2015). The impact of individual relationships on performance and reformation of R&D alliances. Journal of Industrial Engineering and Management, 8(4), 1270.	119 R&D alliances started from 2007-2009 in Catalonia (Spain)	Alliance performance Individual alliance Participants satisfaction Intention to reform the alliance	Trust Conflict at the alliances Commitment Communication behavior	Quantitative Structural Equations
Lin, J., Fang, S., Fang, S., & Tsai, F. (2009). Network embeddedness and technology transfer performance in R&D consortia in Taiwan. Technovation, 29(11), 763-774.	110 companies from the R&D Consortia supported by Government for industry in Taiwan.	Technology advantage Marketing advantage	Network ties Trust Norm	Quantitative Regression analysis