Paper no. 2010/06

A three-stage model of the Academy-Industry linking process: the perspective of both agents

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This version: October 2010

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Lund University
P.O. Box 117, Sölvegatan 16, S-221 00 Lund, SWEDEN
http://www.circle.lu.se/publications
ISSN 1654-3149

WP 2010/06
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Keywords: university-industry interactions; collaboration drivers; channels of interaction; benefits; innovation policy; developing countries; Mexico.

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1 *Introduction*

The role of universities and public research centres, hereafter public research organizations (PRO),[3] is evolving along time, from the formation of human resources and knowledge generation to a more oriented focus of solving problems and attending social needs. There is plenty of evidence that PRO can make important contributions to increase firms' economic performance and attend social needs in both developed and developing countries (Vessuri, 1998; Casas, de Gortari and Luna, 2000; Cohen, Nelson and Walsh, 2002; Arocena and Sutz, 2005; Albuquerque *et al*, 2008; Bekkers and Bodas Freitas, 2008; Perkmann and Walsh, 2009).

PRO-industry (PRO-I) interactions are seen as one of the key elements of the National System of Innovation (NSI). However, it is broadly recognised that PRO have evolved at different pace and with limited interactions in developing countries (Cimoli 2000; Lall and Pietrobelli, 2002; Cassiolato, Lastres and Maciel, 2003; Muchie, Gammeltoft and Lundvall, 2003; Lorentzen 2009; Dutrénit et al, 2010). On one hand, firms do not see academy as a primary source of knowledge and partner for innovation activities, on the other, academic researchers are more likely to be engaged in basic research than in technology development projects. Thus the promotion of stronger PRO-I interactions can play an important role to consolidate NSI in developing countries, as they can promote virtuous circles in the production and diffusion of knowledge.

There is an increasing literature regarding PRO-I interactions that approaches several relevant issues, such as drivers, channels of interaction and perceived benefits, amongst others. Authors focus either on academy (Melin, 2000; Bozeman and Corley, 2004; D'Este and Patel, 2007; Boardman and Ponomariov, 2009), or on firms perspective (Laursen and Salter, 2004; Hanel and St-Pierre, 2006; Fontana, Geuna and Matt, 2006; Mathews and Mei-Chih, 2007; Ayadi, Rahmouni and Yildizoglu, 2009); while some studies have analysed PRO-I interactions from both perspectives (Carayol, 2004; Bekkers and Bodas Freitas, 2008; and Intarakumnerd and Schiller, 2009; Dutrénit, De Fuentes and Torres, 2010; Arza and Vazquez, 2010; Fernandes et al, 2010; Orozco and Ruíz, 2010). Three stages of the linking process can be identified: the engagement in collaboration, the knowledge transfer during collaboration, and obtaining benefits from collaboration. Usually authors focus on one of two of these stages, but they do approach the links between the three. This paper uses the two agents approach and aims to perform a systematic analysis of the nature of PRO-industry interactions across the three stages of the linking process. We are interested on identifying the effect of drivers to collaborate on knowledge transfer through different channels of interaction, and the relative effectiveness of these channels on the benefits perceived by the agents. We argue that different drivers of interaction favor specific types of channels, and these generate specific benefits for each agent.

[3] In this paper we use PRO to refer to universities and public research centers. We are aware that these institutions may differ in relation to their role in the NSI, the knowledge production process, among others characteristics; however in the Mexican case, researchers working at these two types of organizations confront a set of common incentives that contribute to explaining why and how they tend to interact.

The conceptualization of three stages of the linking process is relevant for innovation policy, particularly for those programs oriented to foster PRO-I interactions. Such programs have hardly recognized that agents differ according to their drivers to be engaged in collaboration. They have largely looked for increasing knowledge flows from PRO to industry through joint and contract research, but they do not acknowledge other channels that can be important according to the agents perspective, such as sharing tacit and codified knowledge, human resources mobility or training, amongst others. In addition, channels of interaction differ in terms of their relative effectiveness on the benefits obtained by both agents. This may also be taken into account by policymakers. Thus, differences between both perspectives along the three stages are important to understand the evolution of PRO-I interactions and promote specific policies to strengthen them.

This study is based on original micro data collected through two surveys to analyze PRO-I interactions carried out in Mexico during 2008.[4] One focuses on R&D and product development managers of firms and the other on academic researchers. Based on the methodology of three stages proposed by Crépon, Duguet and Mairesse (1998),[5] we build two models, one for researchers and one for firms, to identify the effect of drivers to collaborate on channels of interaction and the effect of these channels on the benefits perceived from interaction.

This paper is divided in five sections, following this introduction, the second section reviews different bodies of literature that approach the issues discussed here. Section three describes the strategy for data gathering and methodology. Section four presents and discusses the empirical evidence and section five concludes.

2 *Conceptual framework: PRO-industry interactions*

As we focus on the analysis of three stages of the linking process, this section seeks to present a review of the literature that analyze PRO-industry interactions at any of the stages of the linking process.

2.1 *Stage 1: Why do PRO and firms engage in collaboration?*

It is widely recognized that PRO-I interactions represent an important factor for innovation and technology development (Cohen, Nelson and Walsh, 2002). Some authors argue that the nature of interactions change as the country develops, as they reflect a co-evolution of factors which depend on the context, incentives and agents' specificities, particularly their absorptive capacities and embedded culture (Mowery and Sampat, 2005; Albuquerque *et al*, 2008). Following international trends, innovation policy in

[4] This study is based on an international research project titled "Interactions between universities and firms: searching for paths to support the changing role of universities in the South", sponsored by the IDRC (Canada) and developed under the umbrella of the Catching up project.
[5] Crépon, Duguet and Mairesse (1998) analyzed the links between research investment, innovation and productivity at firm level. They built a structural model that analyzes productivity by innovation output and innovation output by research investment.

developing countries has recently focused on fostering PRO-I interactions by reproducing programs initially designed for developed countries. It does not clearly recognize neither the differences in the initial conditions nor that both agents respond to different incentives, as academic researchers function within an academic logic, while firms' depend on business logic. In fact, PRO and firms collaborate for different reasons; for instance, PRO are interested on getting new sources of founding and ideas for future research, sometimes to be able to publish papers (Meyer-Krahmer and Schmoch, 1998; Lee, 2000; Welsh et al, 2008; Perkman and Walsh, 2009); while firms are interested on identifying potential employees and accessing to sources of knowledge, which can lead to industrial applications (Adams et al, 2003; Arvanitis, Sydow and Woerter, 2008). In this sense, differences between both perspectives are important to understand the evolution of PRO-industry interactions and promote specific policies to strengthen such interactions.

Studies analyzing the drivers of PRO-I interaction from the firm's perspective have found that structural, behavioral and policy related factors are the most important drivers to interact. Structural factors include firm's age (Eom and Lee, 2009; Giuliani and Arza, 2009); firm's size (Cohen et al, 2002; Santoro and Chakrabarti, 2002; Hanel and St-Pierre, 2006); technological intensity and industrial environment (Laursen and Salter, 2004; Hanel and St-Pierre, 2006; Segarra-Blasco and Arauzo-Carod, 2008; Tether and Tajar, 2008) and being part of a group (Tether and Tajar, 2008: Eom and Lee, 2009). Behavioral factors include the kind of research and development (R&D) activities performed by the firms (Segarra-Blasco and Arauzo-Carod, 2008), the intensity of R&D (Laursen and Salter, 2004; Eom and Lee, 2009; Torres et al, 2009), and openness strategy to generate new ideas (Laursen and Salter, 2004; Dutrénit, De Fuentes and Torres, 2010). Policy related factors include supporting incubators (Nowak and Grantham, 2000; Etzkowitz et al, 2005), fostering industrial innovative clusters (Sohn and Kenney, 2007), and starting joint research projects. In addition, several authors have found that firms that invest highly in R&D are more prone to have higher absorptive capabilities to learn and interact with universities (Cohen et al., 2002; Fontana et al., 2006) than otherwise.

From the Academy perspective, some studies have found that institutional and individual factors explain the likelihood of engagement in PRO-industry interactions. Institutional factors include institutional affiliation -researchers working in public research centres (PRC) have more chance to connect than those working in universities (Boardman and Ponomariov, 2009), the mission of the university, universities that emphasise entrepreneurship tend to collaborate more with firms than otherwise (Etzkowitz and Leydesdorff, 2000; Mowery and Sampat, 2005), previous technology transfer experience (D'Este and Patel, 2007), scale of research resources and access to different sources of funding for research by the department (Lee, 1996; Schartinger et al., 2002; Colyvas et al., 2002; Bozeman and Gaughan, 2007), and quality of research (Mansfield and Lee, 1996; Schartinger et al., 2002). The set of individual factors includes previous experience in interaction (Bekkers and Bodas Freitas, 2010), academic status and research fields (Friedman and Silverman, 2003; Bercovitz and Feldman, 2003; D'Este and Patel, 2007; Bekkers and Bodas Freitas, 2008; Boardman and Ponomariov, 2009), and academic collaboration (Boardman and Ponomariov, 2009).

2.2 *Stage 2: Which are the main types of knowledge transfer through channels of interaction?*

Several studies focus on the core of the linking process –the interaction stage. Empirical evidence suggests that knowledge flows during PRO-industry interaction through multiple channels. The most frequently recognized channels of interaction are: joint and contract R&D; human resources mobility -students and academics; networking; information diffusion in journals, reports, conferences and Internet; training and consultancy; property rights; incubators; and spin offs. According to Bekkers and Bodas Freitas (2008), the relative importance of the channels is similar amongst firms and academic researchers in Holland, however academic researchers assign more importance to the different channels than firms. In contrast, other authors argue that from the industry perspective, joint R&D projects, human resources, networking, open science, and patenting are the most important channels (Narin, et al, 1997; Swann, 2002; Cohen, Nelson and Walsh, 2002). While from the PRO perspective, joint and contract R&D projects, meetings and conferences, human resources mobility, training and consultancy, and the creation of new physical facilities, are the most important channels (Meyer-Krahmer and Schmoch, 1998; Mowery and Sampat, 2005; D'Este and Patel, 2007; Perkmann and Walsh, 2009). In this direction Dutrénit and Arza (2010) found that in four Latin American countries, there are important differences in the preferred channels of interaction used by both agents.

Channels of interaction can be grouped into different categories according to the degree of formality (Vedovello, 1997 and 1998; Fritsch and Schwirten, 1999; Schartinger et al., 2002; D'Este and Patel, 2007; Perkmann and Walsh, 2009; Eun, 2009), the degree of interaction (Fritsch and Schwirten, 1999, Perkmann and Walsh, 2007; Santoro and Saparito, 2003; Schartinger et al., 2002), the direction of knowledge flows (Schartinger et al., 2002; Arza, 2010) and the potential to obtain applied results (Wright et al., 2008; Perkmann and Walsh, 2009). Perkmann and Walsh (2009) found that some types of formal interaction, such as joint R&D result in academic publications, while this is less true for interactions with more applied objectives, such as contract research and consulting. Arza (2010) argues that bi-directional (e.g. joint and contract research) and commercial (e.g consultancy) channels may be the most effective way to convey novelty and therefore to allow technological upgrading. In this direction, Perkmann and Walsh (2009) assert that the forms of interaction grouped in these channels involve a higher level of articulation than other channels, helping the transmission of tacit knowledge.

From the PRO perspective, empirical evidence shows differences according to the nature and fields of research; researchers focused on applied research tend to favor the use of patents, human resources mobility, and collaborative research, while those involved in basic research favor publications and conferences (Meyer-Krahmer and Schmoch, 1998; D'Este and Patel, 2007; Bekkers and Freitas, 2008). From the viewpoint of industry, Schartinger et al. (2002) emphasize the importance of using different channels as it represents varying strategies to ensure research efficiency, allows access to different types of scientific and technological knowledge, and reflects differences in demand for knowledge in different stages of innovation. However, the emphasis on each channel or group of channels is determined by the motivations to interact, and they usually vary according to the field of knowledge, technology and sector (Cohen *et al.*, 2002; Schartinger et al., 2002; Cohen, Nelson and Walsh, 2002; Laursen and Salter, 2004; Mowery and Sampat, 2005; Hanel and St-Pierre, 2006; Fontana, Geuna and Matt, 2006; Bekkers and Freitas, 2008; Intarakumnerd and Schiller, 2009; Arza, 2010). As different sectors have different knowledge bases and innovation patterns (Pavitt, 1984), they also have different ways to interact with the academy and other sources of knowledge.[6]

2.3 *Stage 3: Which are the main benefits from the interaction?*

Studies have shown that the perceived benefits from interaction differ between firms and PRO. Firms obtain a different perspective for the solution of problems and in some cases perform product or process innovation that without interaction could not have been possible (Rosenberg and Nelson, 1994). Researchers obtain ideas for publication, ideas for future research, test applications of a theory and knowledge exchange, contacts between researchers and firms, a new perspective to approach industry problems and the possibility of shaping the knowledge that is being produced at the academy, and secure funds for the laboratories and supplement funds for their own academic research (Meyer-Krahmer and Schmoch, 1998; Lee, 2000; Welsh et al, 2008).

There are different types of benefits for researchers and firms, and they can be grouped into different forms. From the PRO perspective, Arza (2010) grouped benefits in two main categories, economic and intellectual. Economic benefits refer to obtain research inputs and securing funds for the laboratories, supplement funds for their own academic research, and obtain financial resources (Rosenberg and Nelson, 1994; Lee, 2000; Perkmann and Walsh, 2009). Intellectual benefits refer to knowledge exchange, ideas for new scientific and research projects (Perkmann and Walsh, 2009), formation of human resources, academic publications (Perkmann and Walsh, 2009), scientific discoveries, a new perspective to approach industry problems (Lee, 2000; Perkmann and Walsh, 2009), and the possibility of shaping the knowledge that is being produced (Perkmann and Walsh, 2009).

From the firms' perspective, Arza (2010) groups the benefits in production and innovation. Production benefits refer to new human resources, use resources available at PRO to perform test and quality control, access to different approaches for problem-solving, and contribute to the completion of existing projects. Other authors have also

[6] For biotechnology and pharmaceuticals, Cohen, Nelson and Walsh (2002) found that knowledge transfer by publications is more important. For chemical, different knowledge flows are found important, such as patents, collaborative research and human resources mobility (Schartinger, et al, 2002), and scientific output, informal contacts and students (Bekkers and Bodas Freitas, 2008). For electronics, the most important is human resources, especially through hiring students (Schartinger, et al, 2002; Balconi and Laboranti, 2006).

emphasized the development of new products and process (Rosenberg and Nelson, 1994; Lee, 2000; Cohen, Nelson and Walsh, 2002). Innovation benefits refer to access to highly skilled research teams from PRO, the possibility to shape the knowledge that is being produced at the academy, new R&D projects (Cohen, Nelson and Walsh, 2002), selection or direction of firms' research projects (Eom and Lee 2010), technology licenses, and patents (Lee, 2000), and access to university research and discoveries (Lee, 2000; Cohen, Nelson and Walsh, 2002; Zucker, Darby, and Armstrong, 2002). Cohen, Nelson and Walsh (2002) and Eom and Lee (2010) also found that economic benefits are important for firms, as about a third of industrial research projects in US and Korea use research findings from public research. Monjon and Waelbroeck (2003) found that getting the benefits from collaboration is firm specific and depend on firm's absorptive capacities to identify and exploit external knowledge.

Regarding the relationship between channels and benefits from interaction, most of the authors have analyzed the positive effect of joint and contract R&D on the benefits obtained either by researchers or by firms. Perkman and Walsh (2009) found that joint R&D often results in academic publications, while other types of collaboration with more practical objectives, such as contract research and consultancy, lead to publications only if researchers make efforts to exploit collaboration for research purposes. On the firms' side, Adams et al. (2003), Hanel and St-Pierre (2006) and Arvanitis, Sydow and Woerter (2008) found that PRO-I interactions through R&D brings different types of benefits, such as innovation and productivity increases that have a positive impact on product development. Dutrénit, De Fuentes and Torres (2010) found that bi-directional (e.g. joint and contract research) and traditional (e.g. hiring graduates) channels of interaction bring intellectual benefits to Mexican PRO; while bi-directional, traditional and services (e.g. consultancy) channels bring production and innovation benefits for firms. Using the same analytical framework, other Latin-American countries report some analogous results. Arza and Vazquez (2010) found that bi-directional and services channels bring intellectual benefits, and services channel does it for economic benefits in the case of Argentinean researchers; while traditional and bidirectional channels bring production and innovation benefits for Argentinean firms. Fernandes et al (2010) found that bi-directional, traditional and services channels contribute to both intellectual and traditional benefits for university researchers, and also to production benefits for firms, while bidirectional and traditional channels are relevant for innovation benefits.

In contrast, some works identified disadvantages of PRO-industry interaction. They mention that a greater involvement with industry can corrupt academic research and teaching, keeping away the attention from fundamental research. It can destroy the openness of communication among academic researchers and put restrictions on publishing, which is an essential component of academic research (Rosenberg and Nelson, 1994; Welsh et al, 2008). The positive and negative aspects of interaction have brought some debate about the new role of academy regarding the increasing interaction with industry. Rosenberg and Nelson (1994) argue that, on one hand, universities can and should play a larger and more direct role in assisting industry (mostly firms´ view); while on the other hand, some researchers see these developments as a threat to the integrity of academic research (mostly academics´ view). This discussion is particularly relevant for developing countries, as universities could play an important role for development, which require more orientation towards economic and social needs (Arocena and Sutz, 2005). Welsh *et al* (2008) stress that to maximize the benefits of academic research, require the development of policies that increase interaction, and protect the autonomy and freedom of researchers.

2.4 *Looking at the linking process as a three stages process*

This paper conceptualizes PRO-industry linkages as a process that can be divided into three different stages: i) the engagement in collaboration (e.g. the drivers), ii) the knowledge transfer during collaboration (e.g. knowledge flows through different channels of interaction), and iii) the benefits from collaboration.

The literature mostly approaches these stages independently, and focuses either on one specific channel or link certain channels (mostly joint R&D) and benefits. However, we suggest that there is a connection between the three stages, different drivers to collaborate determine specific types of knowledge flows through certain channels, and these channels also have impact on the specific benefits that agents perceive from interaction. Hence, to obtain a deeper understanding of agents behavior requires a systematic approach of the linking process as a whole following its three stages. Based on micro data of the Mexican case, this paper empirically tests these links from the perspective of both agents. A three stages model for researchers and firms was built, which is based on three equations that allow us to understand the dynamic impact of the variables associated with one stage on the others. The model specification is described in section 3.3.

3 *Methodology*

3.1 *Data collection and sample characteristics*

This study is based on original data collected through two surveys on PRO-I interactions carried out in Mexico during 2008. R&D and product development managers answered the firms' survey. It includes questions about: innovation and R&D activities, sources of knowledge and forms of PRO-I interaction, objectives and benefits from interaction, and perception about the main role of PRO. Researchers working at PRO answered the Academics' survey. This survey includes: researchers and team's characteristics, forms of PRO-I interaction, and personal and institutional benefits from interaction.

Regarding researchers, the sampling frame was constructed from the National Researchers System (NRS) database.[7] Only researchers from six fields of knowledge were included (Physics & Mathematics; Biology & Chemistry; Medicine & Health Sciences; Social Sciences; Biotechnology & Agronomy; and Engineering). Initially the questionnaire was sent to 10,100 researchers by email but the response rate was very low. We turned to a shortlist provided by CONACYT of 2,043 researchers from all the fields of knowledge that are quite active in applying for public grants. We complemented this

[7] The NRS program provides grants both pecuniary (a monthly compensation) and non-pecuniary stimulus (status and recognition) to researchers based on the productivity and quality of their research. It constitutes important incentives to produce papers in ISI journals.

list with 1,380 researchers working in engineering departments of the main PRO to include researchers that are not part of the NRS but tend to have linkages with firms. Finally the response rate was 14%. For this paper, the sample was conformed by 385 researchers ascribed to PRO, 81% of them belong to the NRS, and 61% have links with the industry.

The sample distribution is as follows: 17% Physics & Mathematics, 23% Biology & Chemistry, 6% Medicine & Health Sciences, 24% Biotechnology & Agronomy, and 30% Engineering. 87% of the researchers have a PhD, 7% a master's degree and 6% are graduates. In terms of the institutional affiliation, 58% of researchers are ascribed to universities. Within PRO, researchers from public research centres tend to connect more than those affiliated to universities (75% and 51% respectively). From the total sample, 71% of researchers belong to a research group, and 61% of the research groups have links with firms. Regarding the research type, 52.7% of researchers perform basic science, 26.8% perform applied science and 20.5% perform technology development. On average, the size of research groups is 18 members (including PhD, masters, graduates, technicians and students of different levels, few groups have Post-Docs).

Regarding firms, the sampling frame was constructed from different lists of firms that have participated in different projects or programs managed by federal and regional government agencies, such as fiscal incentives for R&D, and sectoral funds, among others. 1,200 firms integrated the firms' database; 70% of them have benefited from public funds to foster R&D and innovation activities. The response rate was 32.3%. For this paper, the sample was conformed by 325 innovative firms from all manufacturing sectors, non-innovative were excluded. 67% are R&D performers, 42% have obtained fiscal incentives for R&D, and 75% have links with PRO (67% interact with universities and 47% with public research centres). The composition between linked and not linked firms differs between sectors. The characteristics of this sample do not differ from results obtained by the National Innovation Survey of 2006, where half of the innovators perform R&D activities, and 65% use PRO as information source.

Linked firms have larger R&D departments, employ 85% more highly skilled human resources to perform R&D activities and tend to use other information sources more extensively than those without links. Firms that received fiscal incentives for R&D have a higher tendency to interact than otherwise, as 84% of them have links with industry. Firms with foreign investment represent 33% of the total sample; they have about the same tendency to interact than national owned firms (70%). In terms of firm's size, most firms are medium-size (42%) and large (42%), only 16% are micro and small. Micro/small and large firms tend to interact more (80%) than medium-size firms (68%).

Both surveys were voluntary, thus there is probably a bias towards PRO-I interaction regarding those researchers and firms that actually interact and are keener to answer this questionnaire than others. In addition, firms' survey includes a large proportion of firms that have obtained public funds to foster R&D, thus they may perform R&D activities.

3.2 *Construction of variables*

We conducted a systematic analysis of the three stages of the linking process for firms and PRO. The first stage focuses on the analysis of drivers of interaction, we identify the impact of different variables that affect the probability of linking for researchers and firms. The second stage focuses on the analysis of channels of interaction; we identify the impact of different variables that affect the preference of different channels of interaction. We performed the analysis of the second stage only on researchers and firms that actually interact, correcting for a possible selection bias. During the third stage we identify the impact of different variables on the benefits perceived by both agents, during this stage we incorporate the results from stage two to identify the particular impact of each channel of interaction on the benefits from interaction.

The key variables for stage two are channels of interaction and for stage three are benefits from interaction. To build the variable of channels of interaction we rely on a question where researchers and firms evaluated the importance of each form of interaction. 10 forms of interaction were classified into four knowledge channels following a methodology of factor analysis by factor reduction (Table 1).[8] The results of the classification of firms and researchers were similar, however the factor loads for each form of interaction of firms and researchers in the same channel is different.

Table 1 Channels of PRO-industry interaction

Knowledge Channels	Forms of interaction
Information & training (InfoChannel)	Publications Conferences Informal information Training
R&D projects & consultancy (ProjectChannel)	Contract R&D Joint R&D Consultancy
Intellectual Property rights (IPRChannel)	Technology licenses Patents
Human resources (HRChannel)	Hiring recent graduates

To build the variable of benefits for researchers and firms we analyzed a question where researchers and firms evaluated the importance of each benefit from interaction. For firms' benefits we rely on a question where firms evaluated the importance of achieving specific objectives from their interaction with PRO, we only considered the cases where firms evaluated as positive the results from interaction. We identified three types of benefits from interaction following a methodology of factor analysis by factor reduction:

[8] Table A.1 and A.2 in the Annex presents the rotated matrix for channels of interaction for firms and researchers, respectively.

supporting R&D performance benefits (RD), improving non-R&D based capabilities benefits (Cap) and improving quality benefits (Q) (Table 2).[9]

Table 2 Type of benefits for firms

Group of Benefits	Individual Benefits
Supporting R&D performance (RD)	Contract research to contribute to the firms' innovative activities Contract research that the firms do not perform Use resources available at PRO
Improving non-R&D based capabilities (Cap)	Technology transfer from the university Technology advice and consultancy to solve production problems Increase firms' ability to find and absorb technological information Get information about trends in R&D Make earlier contact with university students for future recruiting
Improving Quality (Q)	Perform test for products/processes Help in quality control

To build the variable of researchers' benefits we rely on a question where researchers evaluated the importance of benefits during their interaction with firms. We performed a factor analysis by factor reduction and grouped the benefits into two factors: Economic (E) and Intellectual (I) benefits (Table 3).[10]

Table 3 Type of benefits for researchers

Benefit	Forms
Intellectual (I)	Ideas for further collaboration projects Ideas for further research Knowledge/information sharing Reputation
Economic (E)	Share equipment/instruments Provision of research inputs Financial resources

We also identified different independent variables that affect each one of the three stages of the linking process for researchers and firms: drivers of interaction, channels of interaction and benefits from interaction.

For firms we analyzed variables related to structural factors, such as firms' characteristics (size, sector, technology level and ownership); and related to behavioral factors, such as effort to increase R&D capabilities, innovation strategy, and linking strategy with PRO

[9] Table A.4 in the Annex presents the rotated matrix for firms' benefits.
[10] Table A.5 in the Annex presents the rotated matrix for researchers' benefits. We draw on the concepts proposed by Arza (2010).

(Table 4). Regarding innovation strategy, one of the variables we analyzed was openness strategy. We draw on Laursen and Salter (2004)[11] to build four factors by principal components that express the firm's openness strategy to obtaining information from external sources.[12]

Table 4 Variables for analyzing PRO-industry linkages from the firms' perspective

Broad Concept	Variables	Mean	St. Dev.	Definition of variables	Stage
Collaboration	Collaboration (COLLPRO)	0.754	0.431	Dummy: collaborate=1, do not collaborate=0	1
Channels of interaction	Information & training (InfoChannel) R&D Projects & Consultancy (ProjectChannel) Intellectual property rights (IPRChannel) Human resources (HRChannel)	8.07E-07 -8.67E-07 4.76E-07 -1.52E-06	1 1 1 1	Numerical: Factor loads from factor reduction	2
Benefits from interaction	Supporting R&D performance (RD) Improving non R&D based capabilities (Cap) Improving quality (Q)	1.14E-08 -2.80E-09 -1.23E-08	1.340 1.443 1.631	Numerical: Factor loads from factor reduction	3
Firms' characteristics	Firm size (LNEMPL)	5.330	1.566	Numerical: ln of firms' employees	1
	Technology sector (TECHLEVEL)	0.577	0.255	Categorical: 0.25: low; 0.5: medium-low; 0.75: medium-high; 1: high	1
	Ownership (ownership)	0.329	0.471	Dummy: Foreign investment=1; Otherwise=0	1, 2
Effort to increase R&D capabilities	Human resources in R&D (RATIOEMP)	6.551	11.681	Numerical: Human resources in R&D as % of the total employment	1, 2
	Formalization of R&D activities (FORMAL)	0.745	0.436	Dummy: Formal and continuous R&D activities=1; Otherwise=0	1, 2
Innovation strategy	Fiscal incentives R&D (EF)	0.418	0.494	Dummy: Yes=1; No=0	1, 2
	Openness strategy: Access to open information (F1) Consulting and research projects with other firms (F2) Market (F3) Suppliers (F4)	4.47E-06 -2.27E-06 8.30E-07 3.75E-06	1.000 1.000 1.000 1.000	Factor loads from factor analysis of external sources of information for F1-F4	1
Linking strategy with	Role of university			Categorical: 0.25: without	1

[11] Laursen and Salter (2004) argue that management factors, such as firms´ strategy to rely on different types of information sources, among others, are important drivers to collaborate and get the benefits from academy. They built a variable that reflects firms' search strategies. From a pool of 15 information sources, excluding 'universities' and 'within the firm', they performed a factor analysis using principal components and obtained two factors for openness strategy.

[12] The common explained variance by these factors is 66.1%. See Table A.3 in the Annex for a better description of the factor analysis.

Broad Concept	Variables	Mean	St. Dev.	Definition of variables	Stage
PRO	ROLB: Creation and transfer of knowledge ROLD: Human resources formation	0.792 0.746	0.240 0.259	importance; 0.5: low importance; 0.75: medium importance; 1: high importance.	
	Type of PRO VINCUNIV: links with universities VINPRC: links with public research centres	0.671 0.471	0.026 0.028	Dummy: yes=1, no=0	2
	Duration of links (TIME)	0.808	0.395	Dummy: 0=least than 1 year, 1=one year or more	3

For researchers we analyzed individual factors, such as knowledge skills, academic collaboration; and institutional factors such as institutional affiliation and linking strategy with firms (Table 5).

Table 5 Variables for analyzing PRO-I linkages from the researchers' perspective

Broad Concept	Variables	Mean	St. Dev.	Definition of variables	Stage
Collaboration	Collaboration (collaborate)	0.610	0.488	Dummy: 1 = collaborate, 0 = do not collaborate	1
Channels of interaction	Information & training (InfoChannel) Intellectual property rights (IPRChannel) R&D Projects & Consultancy (ProjectChannel) Human resources (HRChannel)	-1.08E-16 9.87E-17 3.06E-17 -9.64E-17	1 1 1 1	Numerical: Factor loads from factor reduction	2
Benefits from interaction	Benefits from collaboration Intellectual (I) Economic (E)	 1.76E-16 3.77E-17	 1 1	Numerical: Factor loads from factor reduction	3
Knowledge skills	Degree (graduate) (master) (PhD)	0.060 0.070 0.870	0.237 0.256 0.337	Dummy: PhD=1, Master=0 Graduate=1	1, 2
	Type of research (basic) (technology) (applied)	 0.527 0.205 0.268	 0.500 0.404 0.443	Dummy: Basic science=1; Technology development=1; Applied science=0	1
Institutional affiliation	Type of organization (Type)	0.584	0.493	Dummy: 1=University, 0=Public research centres	1, 2
Academic collaboration	Member of a research team (team)	0.712	0.454	Dummy: Yes=1; No=0	1, 2
	Team age (EdadGPO)	7.704	10.557	Numerical	1, 2
	Human resources in the team (RHTeam)	3.325	7.488	Numerical: $RH=\Sigma x_{ij}P_i/N$ Postdoc=0.4, PhD=0.4; PhD students=0.3; Master students and researchers=0.2; undergraduate students,	1, 2

Broad Concept	Variables	Mean	St. Dev.	Definition of variables	Stage
				College researchers and technicians=0.1	
Linking strategy with firms	Importance of linking with firms (ImpVinc)	0.455	0.499	Dummy: Yes=1 (highly important); No=0 (without importance)	1
	Initiative of collaboration (Firm) (Researcher) (both)	 0.081 0.317 0.171	 0.272 0.466 0.377	Dummy: Firms' initiative=1; Both=1; Researcher' initiative=1	3
	Financing projects (Ffirm) (Fresearcher) (FConacyt)	0.330 0.563 0.700	0.471 0.497 0.459	Dummy: Firms' initiative=1; Researcher' initiative=1; Both=1	3

3.3 *The model*

We conceptualized PRO-industry linkages as a systematic process that can be divided into three different stages: i) the engagement in collaboration (e.g. drivers), ii) the knowledge transfer during collaboration (e.g. channels), and iii) the benefits from collaboration (e.g. benefits). We suggest that drivers to collaborate favor specific types of channels of interaction, and specific types of channels also favor certain benefits from interaction.

Our model consists of three equations, one for each stage of the linking process. We used a Heckman two-step estimation model for the first and second stages (Heckman, 1978), which helps to isolate the factors that affect the selection process and reduce the selection bias. In the first stage of the model (drivers), a Probit regression is computed to identify the main drivers that affect the probability of linking. The dependent variable (d_i) is a dummy variable that equals one when the firm or researcher is connected. The vectors of independent variables in these equations are those features of researchers (RD_i) and firms (FD_i) that affect their probability of linking. This stage also estimates the inverse mills ratio for each researcher or firm, which is used as an instrument in the second regression to correct the selection bias. The second equation (channels) is a linear regression to identify the main determinants of the channels of interaction. The dependent variable (c_i) is a *pseudo-continuous* variable that expresses the importance of the channels of interaction. The vectors of independent variables are those features of researchers (RC_i) and firms (FC_i) that determine the specific channels. We conceptualized one equation for each type of channel for researchers and firms. We performed the second equation only on firms and researchers that actually interact, using the inverse mill's ratio from the first equation to correct for a possible selection bias. During the third stage (benefits) we build a linear regression to identify the main determinants to obtain benefits from collaboration. The dependent variable (b_i) is a *pseudo-continuous* variable that expresses the importance of benefits from interaction. The vectors of independent variables are those features of researchers (RB_i) and firms (FB_i) that determine the specific benefits from interaction. We conceptualized one equation for each type of benefits for researchers and firms. During this stage we incorporate the predicted values from each channel of interaction from equation 2. As we identified three types of benefits for firms and two types of benefits for researchers, we have a set of three equations for firms and two equations for researchers. Following this methodology it is possible to identify the impact of drivers on channels of interaction, and the impact of channels on benefits from interaction for each agent.

a) Model for Firms:

(1.1) $d_i = FD_i\beta + \varepsilon_i$
(1.2.1) $c_i Info = FC_i\beta + \varepsilon_i$
(1.2.2) $c_i Project = FC_i\beta + \varepsilon_i$
(1.2.3) $c_i IPR = FC_i\beta + \varepsilon_i$
(1.2.3) $c_i HR = FC_i\beta + \varepsilon_i$
(1.3.1) $b_i RD = \alpha_i c_i + FB_i\beta + \varepsilon_i$
(1.3.2) $b_i Cap = \alpha_i c_i + FB_i\beta + \varepsilon_i$
(1.3.3) $b_i Q = \alpha_i c_i + FB_i\beta + \varepsilon_i$

Where:
d_i is a dummy variable that expresses collaboration with academy for firm *i*.
c_i express four different types of channels of interaction (Information & training, R&D Projects & Consultancy, Intellectual property rights, and Human resources).
b_i express three different types of benefits for firm *i* (Supporting R&D performance, Improving non R&D based capabilities, and Quality).
FD_i is a vector of explanatory variables for drivers of interaction: *human resources in R&D, formalization of R&D and innovation activities, firm size, technology sector, ownership, fiscal incentives for R&D, openness strategy, role of the university for creation of knowledge and entrepreneurship.*
FC_i is a vector of explanatory variables for channels of interaction: *human resources in R&D, formalization of R&D and innovation activities, linkages with universities, linkages with public research centres, ownership, fiscal incentives for R&D.*
FB_i is a vector of explanatory variables for benefits from collaboration: *human resources in R&D, duration of links.*
$\alpha_i c_i$ are the predicted values for equation (1.2), they are associated with each type of channel of interaction (Information & training, R&D projects & consultancy, Intellectual property rights, and Human resources). Table 6 lists the variables used in each equation.

b) Model 2. Researchers´ perspective:

(2.1) $d_i = RD_i\beta + \varepsilon_i$
(2.2.1) $c_i Info = RC_i\beta + \varepsilon_i$
(2.2.2) $c_i Project = RC_i\beta + \varepsilon_i$
(2.2.3) $c_i IPR = RC_i\beta + \varepsilon_i$
(2.2.3) $c_i HR = RC_i\beta + \varepsilon_i$
(2.3.1) $b_i I = \alpha_i c_i + RB_i\beta + \varepsilon_i$
(2.3.2) $b_i E = \alpha_i c_i + RB_i\beta + \varepsilon_i$

Where:
d_i is a dummy variable that expresses collaboration with firms for PRO *i*.
c_i express four different types of knowledge flows (Information & training, R&D projects & consultancy, Intellectual property rights, and Human resources).
b_i expresses two different types of benefits for PRO *i* (intellectual and economic).
RD_i is a vector of explanatory variables for drivers of interaction: *degree*, *importance to linking with firms, type of research, and type of organization.*
RC_i is a vector of explanatory variables for channels of interaction: *degree, type of researcher, type of organization, member of a team, human resources in the team, team age.*
FB_{i} is a vector of explanatory variables for benefits from collaboration: *type of organization, initiative of collaboration.*
$\alpha_i d_i$ is the predicted value for equation (2.1)
$a_i c_i$ are the predicted values for equation (2.2), they are associated with each channel of interaction (Information & training, R&D projects & consultancy, Intellectual property rights, and Human resources). Table 7 lists the variables used in each equation.

4 *Main findings*

Results from our analysis suggest that academy is an important source of knowledge for firms and firms represent an important source of ideas to shape new knowledge that is being produce in academy. However, we observed certain differences along the three stages of the linking process. Firms and PRO have different drivers to collaborate. They have different perspectives regarding the determinants of channels of interaction, and the impact of these channels on specific benefits differs. Also the perceived benefits are specific for firms and researchers.

4.1 *Firms*

Table 6 presents the results of the regression model for equations (1.1), (1.2.1), (1.2.2), (1.2.3), (1.2.4) and (1.3.1), (1.3.2), (1.3.3) for firms.

Table 6 Regression models for firms

	Selection (1.1)	InfoChannel (1.2.1)	Selection (1.1)	ProjectChannel (1.2.2)	Selection (1.1)	IPRChannel (1.2.3)	Selection (1.1)	HRChannel (1.2.4)	RD Benefits (1.3.1)	non R&D Cap Benefits (1.3.2)	Quality Benefits (1.3.3)
aInfoChannel (*a*C1)									-0.833 (0.650)	0.676 (0.725)	1.945** (0.840)
*a*ProjectChannel (*a*C3)									1.291*** (0.436)	-0.465 (0.485)	-0.408 (0.563)
*a*IPRChannel (*a*C2)									0.810** (0.394)	0.178 (0.438)	-0.875* (0.508)
*a*HRChannel (*a*C4)									0.318* (0.240)	0.615** (0.267)	-0.446* (0.309)
Ownership	0.070 (0.192)	-0.253* (0.141)	0.097 (0.200)	0.064 (0.141)	0.181 (0.205)	-0.234* (0.143)	0.064 (0.197)	0.096 (0.134)			
Human resources in R&D (RATIOEMP)	0.011 (0.013)	0.000 (0.004)	0.018 (0.016)	0.005 (0.005)	0.008 (0.013)	0.005 (0.005)	0.015 (0.015)	0.000 (0.005)	0.015** (0.008)	-0.001 (0.009)	-0.004 (0.010)
Formalization of R&D activities (FORMAL)	0.612*** (0.199)	-0.264* (0.166)	0.576*** (0.200)	-0.147 (0.181)	0.638*** (0.199)	0.006 (0.155)	0.650*** (0.197)	0.051 (0.170)			
Fiscal incentives R&D (EF)	0.265* (0.193)	0.121 (0.143)	0.315* (0.196)	0.248* (0.141)	0.338* (0.190)	0.515*** (0.139)	0.313* (0.196	-0.385*** (0.138)			
Type of PRO: University (VINCUNIV)		0.179 (0.214)		0.341** (0.177)		0.113 (0.163)		1.057*** (0.209)			
Type of PRO: PRC (VINCPRO)		0.467*** (0.148)		0.748*** (0.137)		-0.078 (0.136)		0.023 (0.134)			
Firm size (LNEMPL)	0.025 (0.073)		0.042 (0.074)		-0.013 (0.076)		0.012 (0.078)				
Technology sector (TECHLEVEL)	0.211 (0.356)		-0.171 (0.446)		0.186 (0.338)		0.271 (0.352)				
Access to open information (EstAPF1)	0.221** (0.086)		0.145* (0.096)		0.245*** (0.086)		0.175** (0.091)				
Consulting and research projects with other firms (EstAPF2)	0.319*** (0.108)		0.274** (0.100)		0.265*** (0.092)		0.226** (0.099)				
Market (EstAPF3)	0.088 (0.080)		0.027 (0.084)		0.070 (0.082)		0.063 (0.081)				
Suppliers (EstAPF4)	0.236** (0.090)		0.149* (0.102)		0.234** (0.088)		0.272*** (0.090)				
Role of the university: creation and transfer of knowledge (ROLB)	1.148*** (0.388)		1.281*** (0.397)		0.937** (0.401)		1.003** (0.426)				
Role of the university:	-0.072 (0.355)		-0.109 (0.385)		-0.082 (0.344)		0.246 (0.390)				

human resources formation (ROLD)											
Duration of links (TIME)									0.185 (0.248)	0.569** (0.276)	-0.341 (0.320)
cons	-0.873* (0.566)	-0.056 (0.299)	-0.873* (0.577)	-0.572** (0.285)	-0.559 (0.593)	-0.123 (0.224)	-1.034** (0.558)	-0.656** (0.299)	-0.356* (0.229)	-0.198 (0.255)	0.473* (0.295)
Observations		310		310		310		310			
Censored		69		69		69		69			
Wald Chi2(15)		19.67		48.01		21.70		31.63			
Prob>chi2		0.003		0.000		0.001		0.000			
athrho		-0.604		-0.712		-0.738		-0.608			
lnsigma		0.002		-0.003		0.042		-0.023			
rho		-0.540		-0.612		-0.628		-0.543			
sigma		1.002		0.997		1.043		0.977			
lambda		-0.541		-0.610		-0.655		-0.531			
Wald test of indep. eqns. (rho = 0):		9.41		4.12		8.58		5.53			
*p ‹ 0.1; **p ‹ 0.05; ***p ‹ 0.005											

According to the results from our analysis for firms, the most important drivers for collaboration are related to innovation capabilities (formalization of R&D activities), linkages strategy with PRO (role of the PRO regarding the creation and transfer of knowledge), followed in importance by innovation strategy (fiscal incentives and openness strategy -open science, consulting and research projects with other firms, and suppliers). It is important to mention that each factor of the openness strategy have slightly a different impact on the drivers to collaborate according to the type of channel associated. Thus, openness strategies related to access to open information and suppliers are more significant for the IPRChannel, InfoChannel and HRChannel than for the ProjectChannel. These results confirm those obtained by other authors; Segarra-Blasco and Arauzo-Carod (2008) found that firms' cooperation activities are related to characteristics of the sector and firms, such as R&D intensity, access to public funds for R&D activities, amongst others. Bekkers and Bodas-Freitas (2010) found that public incentives for R&D are important determinants for collaboration. Laursen and Salter (2004) found that openness strategy represents an important factor to increase collaboration as it increases firms' absorptive capacities. However, contrary to what other authors have found (Cohen et al, 2002; Santoro and Chakrabarti, 2002; Laursen and Salter, 2004; Hanel and St-Pierre, 2006; Segarra-Blasco and Arauzo-Carod, 2008; Tether and Tajar, 2008), factors such as the ratio of employees in R&D, and some structural factors, such as firm size and technology sector, are not important determinants for collaboration for the Mexican case. Our results suggest that behavioral factors related to R&D activities (innovation capabilities and innovation strategy) are more important drivers for interaction than structural factors related to firm size, technology sector and ownership.

We observe that the coefficients of the four different selection equations (1.1) do not vary greatly. Thus the results of these equations reflect a robust Heckman model.

Previous empirical evidence suggests that the most important channels of interaction are related to the ProjectChannel (particularly joint R&D projects), HRChannel (mobility), InfoChannel (particularly open science), and IPRChannel (patents) (Narin, et al, 1997; Swann, 2002; Cohen, Nelson and Walsh, 2002). Less has been done regarding the analysis of the individual determinants of these channels. However, several authors argue that the degree of formality, the degree of interaction, the direction of knowledge flows and the potential to obtain applied results play an important role for specific types of knowledge. We contribute to the analysis of the determinants of channels of interaction by identifying the role played by the effort to increase R&D capabilities, the linking strategy with PRO, firms' characteristics, and the innovation strategy on the likelihood of using them.

In this direction, the results from equations (1.2.1), (1.2.2), (1.2.3) and (1.2.4) suggest that each explanatory variable for channels of interaction have a different impact on each type of channel. The most important determinant for the InfoChannel is associated with having linkages with public research centres, followed by ownership and formalization of R&D activities, which have a negative coefficient. Firms are more prone to interact with PRC than with universities to access information. National firms tend to use more actively the InfoChannel from local PRO than foreign owned companies. On the other hand, the results suggest that formal activities of R&D have a negative effect on the InfoChannel, probably because formal R&D activities encourage the creation and accumulation of knowledge, decreasing the dependence of external information. These results suggest that firms' structural and behavioral characteristics as well as linkages with PRC are important determinants for knowledge channels in the form of information & training (publications, conferences, informal information and training).

Regarding the ProjectChannel, we found that the most important determinants for this channel are associated with having linkages with public research centres and universities, followed by the use of fiscal incentives for R&D. These results suggest that firms establish links either with universities or PRC to perform R&D projects and obtain consultancy, and that the use of fiscal incentives encourage PRO-Industry interaction through specific research projects, creating a virtual circle of creation and diffusion of knowledge.

Concerning the IPRChannel, we found that the use of fiscal incentives is an important determinant for this channel, while firm ownership has a less significant and negative impact on the IPRChannel. These results suggests that firms that obtain fiscal incentives for R&D interact more with PRO and tend to patent more. However, firms with foreign investment do not tend to use this channel as much as national owned firms, probably as a result of their access to foreign technologies from subsidiaries or from interactions with foreign PRO.

The results from the HRChannel suggest that links with universities are important determinants of this channel, thus if the firm has linkages with universities, it is more likely to get this type of knowledge flows. On the other hand, the increase of fiscal incentives that firms may obtain has a negative effect on the amount of recent graduates hired by firms. A possible explanation is that firms require experienced, highly skilled human resources and not recently graduates to perform complex projects, thus they change the structure of their demand of human resources.

From equations (1.3.1), (1.3.2) and (1.3.3) we found that the four channels of interaction are important determinants for obtaining benefits from collaboration, but they have different impacts on each type of benefit. Regarding RD benefits, the most important determinants are those channels related to R&D projects and consultancy, followed by Property rights, and Human resources. These results are similar to those found by Adams et al. (2003), Arvanitis, Sydow and Woerter (2008) and Dutrénit, De Fuentes and Torres (2010) regarding the fact that PRO-I interactions through R&D brings innovation and productivity increases that have a positive impact on innovation activities as firms engage in more formal R&D activities with PRO. Although a behavioral factor such as human resources in R&D is not an important determinant to collaborate, it represents an important determinant to get this type of benefits. Regarding the non-R&D capabilities benefit, we found that the HRChannel and the duration of linkages are significant and important determinants for this type of benefits. Interaction through recent graduates plays a key role to obtain firms' absorptive capacities through non-R&D mechanisms, and long time interactions are important to obtain this type of benefits. As this channel refers to non-R&D based capabilities is not surprising to find that the ProjectChannel and the IPRChannel do not play a significant role to get this type of benefits. As for the Quality benefits, we found that the InfoChannel is an important determinant for this type of benefits. However, we also found that the IPRChannel and the HRChannel play a negative role to get this type of benefits, which suggest that interaction with PRO through patents or graduates do not necessarily have an impact on quality control. These results emphasize the fact that each type of channel of interaction has different impacts on the benefits from collaboration, and contribute to the results found by Dutrénit, De Fuentes and Torres (2010), Arza and Vazquez (2010), Fernandes et al (2010) and Orozco and Ruíz (2010).

To sum up, our results for firms suggest that firms' behavioral characteristics are important drivers of interaction. Thus, to promote interaction between PRO and firms is important to encourage factors associated with efforts to increase R&D capabilities, innovation strategy and linking strategy with PRO. Behavioral characteristics associated with formal R&D and human resources in R&D tend to have more interaction with PRO through the IPRChannel, and they tend to get more RDBenefits. RD benefits (joint and contract R&D and use of facilities) can be triggered through the ProjectChannel, the IPRChannel and the HRChannel. To promote this type of benefits is important to strengthen fiscal incentives and linkages with PRO (both public research centers and universities). Non-R&D capabilities benefits (technology transfer, technology advice, absorptive capacities, technology forecast and human resources) can be triggered through the HRChannel. Thus, to promote this type of benefit is important to encourage firms' behavioral characteristics and collaboration with PRO, links with universities can bring a positive impact to access graduates. Quality benefits (perform test for products and processes and quality control) are triggered through the InfoChannel, thus, strengthening firms' behavioral characteristics and links with PRC can bring positive results for this type of benefits.

4.2 *Researchers*

Table 8 presents the results of the regression model for equations (2.1), (2.2.1), (2.2.2), (2.2.3), (2.2.4) and (2.3.1), (2.3.2) for researchers.

Table 7 Regression models for researchers

	Selection (2.1)	InfoChannel (2.2.1)	Selection (2.1)	IPRChannel (2.2.2)	Selection (2.1)	ProjectChannel (2.2.3)	Selection (2.1)	HRChannel (2.2.4)	EconomicB (2.3.1)	IntelectualB (2.3.2)
aInfoChannel (*a*C1)									0.023 (0.427)	-0.808* (0.432)
*a*IPRChannel (*a*C2)									0.412* (0.240)	-0.225 (0.243)
*a*ProjectChannel (*a*C3)									-0.176 (0.398)	0.571* (0.403)
*a*HRChannel (*a*C4)									-3.386** (1.522)	2.825* (1.541)
Graduate (graduate)	0.682* (0.454)	-0.041 (0.350)	0.334 (0.367)	0.911** (0.344)	0.622* (0.432)	-0.459* (0.325)	0.711* (0.459)	0.043 (0.344)		
PhD (phd)	-0.049 (0.294)	-0.100 (0.281)	-0.016 (0.260)	0.462* (0.283)	-0.067 (0.284)	-0.092 (0.266)	-0.044 (0.286)	-0.031 (0.269)		
Type of research: basic (basic)	1.092*** (0.165)	0.464** (0.220)	1.010*** (0.168)	0.844*** (0.287)	1.094*** (0.165)	0.655*** (0.223)	1.084*** (0.166)	-0.001 (0.326)		
Type of research: technology development (technology)	1.394*** (0.231)	0.228 (0.254)	1.522*** (0.262)	1.075*** (0.314)	1.377*** (0.224)	1.042*** (0.260)	1.386*** (0.228)	-0.080 (0.383)		
Type of organization (Type)	-0.447*** (0.149)	0.024 (0.145)	-0.475*** (0.141)	-0.715*** (0.165)	-0.446*** (0.145)	-0.142 (0.139)	-0.451*** (0.148)	0.365** (0.159)	1.465** (0.650)	-1.015* (0.658)
Member of a research team (team)		-0.063 (0.182)		0.440*** (0.165)		-0.284* (0.169)		0.161 (0.177)		
Team age (EdadGPO)		0.002 (0.006)		-0.002 (0.004)		-0.015*** (0.003)		0.004* (0.003)		
Human resources in the team (RHTeam)		-0.002 (0.007)		0.003 (0.005)		0.011* (0.006)		-0.004 (0.006)		
Importance of linking with firms (ImpVinc)	0.311** (0.143)		0.012 (0.126)		0.328** (0.129)		0.235* (0.146)			
Initiative of collaboration: firm (firm)									0.481** (0.241)	0.316* (0.243)
Initiative of collaboration: researcher (researcher)									0.350** (0.185)	0.573*** (0.188)
Initiative of collaboration: both (both)									0.792*** (0.205)	0.592*** (0.207)
cons	-0.417 (0.326)	-0.435 (0.410)	-0.239 (0.292)	-2.010*** (0.419)	-0.405 (0.317)	-0.641* (0.389)	-0.378 (0.319)	-0.411 (0.530)	-1.480** (0.563)	0.392 (0.570)
Observations		382		382		382		382		
Censored		150		150		150		150		
Wald Chi2(15)		6.61		49.76		61.00		11.44		
Prob>chi2		0.579		0.000		0.000		0.178		

athrho		0.587		1.826		0.937		0.247		
lnsigma		0.040		0.295		0.059		-0.024		
rho		0.527		0.949		0.734		0.242		
sigma		1.041		1.343		1.061		0.976		
lambda		0.549		1.275		0.779		0.237		
Wald test of indep. eqns. (rho = 0):		6.850		16.750		16.330		0.340		
*p ‹ 0.1; **p ‹ 0.05; ***p ‹ 0.005										

From the researchers perspective, our results confirm certain findings by other authors, as we found that individual factors such as type of research (Friedman and Silverman, 2003; Bercovitz and Feldman, 2003; D’Este and Patel, 2007, Boardman and Ponomariov, 2009, Bekkers and Bodas Freitas, 2008) and degree, and institutional factors such as institutional affiliation (Boardman and Ponomariov, 2009) and linking strategy with firms are important determinants to collaborate. However, some differences arise. Researchers without postgraduate degree and those working in a public research centre are more likely to connect with industry than otherwise. Researchers that carry out basic science and technology development tend to connect more than those that carry out applied research, similar results were found by Dutrénit, De Fuentes and Torres (2010). This is quite particular to the Mexican case. The incentives structure (NRS program) and the resources scarcity seem to stimulate basic scientists to interact with industry, particularly by accessing to public funds that foster interaction. Linking strategy with firms seems to affect particularly those drivers of interaction related to the InfoChannel, ProjectChannel, and to a lower extent to the HRChannel.

Previous empirical evidence from the researcher perspective suggests that consultancy, joint and contract R&D projects (ProjectChannel); training, meetings and conferences (InfoChannel); human resources mobility (HRChannel); and physical facilities are the most important channels of interaction (Meyer-Krahmer and Schmoch, 1998; D’Este and Patel, 2007; Bekkers and Freitas, 2008). From our model, we contribute by identifying the most important determinants for these channels. We found that if researchers perform basic research they are more prone to transfer knowledge through the InfoChannel than if they perform applied research or technology development. For the IPRChannel and ProjectChannel, we found that if researchers perform basic research or technology development they tend to use more these channels with firms. We also found that academic collaboration is an important determinant for these channels. Research teams have a high and significant coefficient for the IPRChannel, while human resources in the team shows a moderate and positive coefficient for the ProjectChannel. Particularly for the IPRChannel, researchers with PhD degree that perform basic research and technology development, working at PRC are important determinants for this type of channel. Similar to the firms’ model, the results associated with the HRChannel suggest that universities play a critical role to form high quality human resources, but in this case the fact that they have participated in consolidated research groups represents an important means for knowledge flows.

From equations (2.3.1) and (2.3.2) we found that three of four channels of interaction are important determinants for obtaining benefits from collaboration, IPRChannel, ProjectChannel and HRChannel, but they have different impacts on each type of benefit. Regarding intellectual benefits, those channels of interaction associated with R&D projects and consultancy and Human resources have a positive impact on intellectual benefits for researchers, but channels associated with Information and training have a negative impact on intellectual benefits. Thus, to increase intellectual benefits would require fostering schemes to improve knowledge flows through property rights and human resource channels. We also observed that the InfoChannel has a negative impact on intellectual benefits, which can be associated with the pattern predicted by Rosenberg and Nelson (1994) and Welsh et al (2008), as they argue that a greater involvement with industry can corrupt academic research and teaching, keeping away the attention from fundamental research, and a greater involvement with industry can put restrictions on publishing. Regarding economic benefits, our results suggest that the channel associated with property rights is the only channel determinant for this type of benefits, while the HRChannel plays a negative role. Other important determinants for intellectual and economic benefits are related to the initiative to collaborate. In both cases, the agent that started the collaboration does not represent an important difference to obtain these benefits, which suggests that once the collaboration has started, either by the firm or the researcher, intellectual and economic benefits are expected. However, in the case of obtaining intellectual benefits, if the initiative is taken either by the researcher or by both agents is better than otherwise. It means that the involvement of the researchers contribute to increase this type of benefits.

To sum up, individual and institutional factors are important drivers to collaborate. As it was found in a previous work (Dutrénit, De Fuentes and Torres, 2010), researchers with bachelor degree are important determinants to start the collaboration, but once the collaboration has started, researchers with postgraduate degrees play an important role to stimulate certain channels of interaction, such as the IPRChannel. The InfoChannel neither play an important role to get intellectual nor economic benefits from collaboration, but the other three channels analyzed does have slightly significant and positive impact on intellectual and economic benefits. Related to the intellectual benefits, the ProjectChannel and HRChannel are important determinants for this type of benefits, together with who takes the initiative to collaborate firms or researchers. To promote this type of benefit is important to foster interactions leaded by postgraduate researchers (master or PhD degree), particularly if they are part of a research team. Regarding economic benefits, the IPRChannel together with the initiative to collaborate and type of PRO are important determinants for this benefit. Thus, to promote economic benefits is important to foster interaction by researchers that perform basic research and technology development, particularly if they are part of a research group affiliated to a PRC.

5 *Conclusions*

This paper identified different perceptions from researchers and firms along the three stages of the linking process. The agents follow different motivations to interact, value different types of knowledge and obtain different benefits from interaction; the interaction between the three stages of the linking process varies. This paper explored the impact of drivers to collaborate on channels of interaction and the impact of channels on the benefits perceived from collaboration for both agents -researchers and firms.

Our results related to drivers to collaborate confirm other empirical results obtained by several authors that analyze this stage of the linking process either for firms or for researchers. The main drivers for firms to collaborate are associated with behavioral factors, rather than to structural factors. Within behavioral factors, we found innovation strategy (Laursen and Salter, 2004; Bekkers and Bodas Freitas, 2008) and R&D capabilities (Laursen and Salter, 2004; Segarra-Blasco and Arauzo-Carod, 2008; Eom and Lee, 2009; Torres et al, 2009) as important drivers to collaborate. The most important drivers to collaborate for researchers are associated with both, individual and institutional factors. Within individual factors we found knowledge skills (D'Este and Patel, 2007, Boardman and Ponomariov, 2009, Bekkers and Bodas Freitas, 2008); and within institutional factors we found institutional affiliation and linking strategy. Thus to promote interaction is important to develop policies focused to foster firms' R&D activities and their openness strategy, particularly the one associated to open information and interaction with competitors and suppliers; as well as to strengthen the current fiscal incentives system as an important tool to promote collaboration with academia. For the case of researchers, we found different challenges, associated with individual and institutional factors. Researchers with first degree tend to interact more than researchers with postgraduate degree, but once the interaction has started, researchers with postgraduate degrees obtain more benefits, thus is important to find the right stimulus linked to the NRS for postgraduate researchers to promote interaction. Researchers affiliated to public research centres tend to interact more than researchers affiliated to universities, the challenge here is twofold, to design specific stimulus at the NRS to promote interaction for university researches and to create and strengthen technology transfer offices in Universities.

Regarding channels of interaction we found that the impact of different variables differs for each channel of interaction. For the firms' perspective we found that structural and behavioral factors affect differently each specific channel. According to our results the most important determinants are fiscal incentives, links with universities and PRC and ownership. Fiscal incentives for R&D, have a positive effect on the IPRChannel and the ProjectChannel, but play a negative effect on the HRChannel. Thus we can argue that fiscal incentives play an important role in transferring knowledge that is associated with long-term and intensive interactions. Links with universities have a positive effect on the ProjectChannel and the HRChannel, while links with PRC affects positively the InfoChannel and ProjectChannel. National owned firms are particularly important for the InfoChannel and the IPRChannel. On the other hand, we found that formal R&D activities have a negative effect on the likelihood of using the InfoChannel.

From the researchers' perspective we also found that different variables associated with individual factors such as knowledge skills and academic collaboration, and institutional factors such as institutional affiliation have different impact on channels of interaction. Researchers that perform basic research favor the InfoChannel, IPRChannel and the Project Channel, while researchers that perform technology development favor the IPRChannel and ProjectChannel. Academic collaboration is particularly important for the IPRChannel, which suggest that research groups represent an important source of knowledge for long-term linkages associated with technology transfer, but plays a negative role on the ProjectChannel. Group experience is particularly important for the InfoChannel, but has a negative effect on the ProjectChannel. Human resources in the team is an important determinant for the ProjectChannel. These results suggest that for longer time and knowledge intensive interactions, being part of a team is not enough, and the specific skills and experience of the research team plays a key role for successful collaborations. Institutional affiliation is particularly important for the IPRChannel (PRC) and for the HRChannel (universities). This result suggests that the type of institution has an important impact on the type of knowledge flows (see Fernandes et al, 2010).

From the results mentioned above, we found that to promote each specific channel of interaction is important to look at the process as a whole in order to design the right policies that strengthen each channel of interaction. Firms' behavioral factors play an important role for most of the channels of interaction; however, we can identify two main challenges. On one hand, fiscal incentives for R&D play a negative role for the HRChannel, thus it is important to incorporate the right schemes into these type of incentives to promote the interaction of graduate students as a mechanism of knowledge transfer. On the other hand, and on line with results by other authors (Laursen and Salter, 2004; Segarra-Blasco and Arauzo-Carod, 2008; Eom and Lee, 2009; Torres et al, 2009), we found that formalization of R&D activities is an important driver for interaction, but they have a negative effect if any on channels of interaction, which suggest that PRO need to engage in longer term interactions in order to create virtual circles of knowledge transfer. For the case of researchers we found that individual factors, particularly those associated with knowledge skills are particularly important for the InfoChannel, IPRChannel, and ProjectChannel, which suggest the importance that knowledge skills play in the knowledge transfer process. The challenge here to promote channels of interaction is related to institutional factors, particularly with academic collaboration. Our results suggests that there are different opportunities to promote academic interaction, such as those related to foster the creation of research groups integrated by researchers with different degrees and research interests.

Regarding the third stage of the linking process, the results confirm that firms and researchers perceive different benefits from interaction. From the firms' perspective we found that the four channels of interaction play an important role to obtain the benefits from collaboration. However, ProjectChannel and IPRChannel are more important for RD benefits, HRChannel for non-R&D Capabilities benefits and InfoChannel for Quality benefits. The duration of links and human resources in R&D also play an important role to get the benefits from interaction. Thus we argue that by promoting long-term PRO-I linkages engaging highly skilled human resources will bring positive benefits from increased interaction and more complex forms of knowledge flows. From the researchers' perspective we found that IPRChannel, HRChannel and ProjectChannel are important determinants to obtain either intellectual or economic benefits. However, the ProjectChannel and the HRChannel are important for intellectual benefits; the InfoChannel plays a negative effect for intellectual benefits, which can be associated to some of the negative effects of collaboration predicted by Rosenberg and Nelson (1994) and Welsh et al (2008). The IPRChannel is important for economic benefits, while the HRChannel has a negative effect on economic benefits. Other variables, such as who takes the initiative to collaborate are important determinants to get the benefits from collaboration.

Overall, the results suggest that once collaboration has started, different flows of knowledge occur through the four channels of interaction. But several differences confirm the specific patterns of interaction for researchers and firms. The ProjectChannel, IPRChannel and HRChannel play a key role for longer-term benefits for firms associated to increase R&D and non R&D capabilities, which confirms the results by Cohen, Nelson and Walsh (2002) and Eom and Lee (2010). On the other hand, the InfoChannel is important for shorter-term benefits associated to quality control (Arza, 2010). For researchers, the ProjectChannel and the HRChannel are particularly important for longer-term benefits, associated to new research ideas

(Perkmann and Walsh, 2009), while the IPRChannel is important for short-term benefits, associated to different sources of financing (Rosenberg and Nelson, 1994; Lee, 2000; and Perkmann and Walsh, 2009).

Benefits from collaboration play a crucial role on the linking process; we can argue that positive benefits stimulate further collaboration between firms and PRO. From this work we argue that if the main interest is to promote long-term benefits associated with R&D benefits for firms and intellectual benefits for researchers, it is important to encourage the ProjectChannel, IPRChannel and HRChannel. On the other hand, if the interest is to promote short-term benefits associated with Product/Process Quality for firms and economic benefits for researchers, the channels that have an important impact of these benefits are the InfoChannel and IPRChannel. Short-term benefits may be a way to identify the advantages of PRO-I interaction and induce changes in agents' behaviors that can conduct towards long-term benefits.

To promote and strengthen innovative linkages, policymakers should put emphasis on promoting activities related to different forms of interaction looking for the best articulation of knowledge supply and demand. Alignment of incentives for both firms and researchers, and the design of creative policies encouraging the mutual reinforcement of interaction between these two agents are required. This work shows that by promoting the right incentives to increase firms' formalization of R&D activities and the openness strategy will have an important effect in strengthening PRO-I linkages.

Annex

Table A.1 Knowledge channels. Firms

Component	Channel 1. Information & Training	Channel 2. R&D Projects & Consultancy	Channel 3. Property rights	Channel 4. HR
Publications	0.747	0.192	0.465	0.083
Conferences	0.761	0.303	0.322	0.175
Informal information	0.697	0.459	0.011	0.236
Training	0.519	0.225	0.48	0.376
Contract R&D	0.261	0.820	0.275	0.215
Consultancy	0.415	0.605	0.455	0.262
Joint R&D	0.317	0.808	0.308	0.168
Technology licenses	0.307	0.351	0.757	0.283
Patent	0.233	0.301	0.822	0.235
Hiring students	0.221	0.194	0.287	0.699

Extraction Method: Principal Factor Analysis.
Rotation Method: Varimax with Kaiser Normalization.
Rotation converged in 3 iterations.
Explained variance: 76.9%

Table A.2 Knowledge channels. Researchers

Component	Channel 1. Information & training	Channel 2. Property rights	Channel 3. R&D Projects and Consultancy	Channel 4. HR
Publications	.675	.393	.343	.180
Conferences	.852	.074	.103	.202
Informal information	.743	.229	.309	.050
Training	.586	.361	.452	.185
Technology licenses	.230	.854	.241	.153
Patents	.192	.855	.209	.204
Contract R&D	.202	.216	.770	.290
Consultancy	.237	.174	.800	.067
Joint R&D	.388	.416	.529	.076
Hiring students	.255	.280	.237	.877

Extraction Method: Principal Factor Analysis.
Rotation Method: Varimax with Kaiser Normalization.
Rotation converged in 3 iterations.
Explained variance: 77.4%

Table A.3 Firms' openness strategy. Rotated Component Matrix.

Linkages	Access to open science	Consulting and research projects with other firms	Market	Suppliers
Suppliers	.183	.142	.076	.911
Customers	.061	.024	.876	.137
Competitors	.433	.182	.509	-.226
Joint or cooperative projects with other firms	.114	.626	.365	.165
Consultancy with R&D firms	.016	.849	-.076	.059
Publications and technical reports	.603	.449	.090	-.095
Expos	.693	-.088	.204	.119
Internet	.773	.090	-.011	.222

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
Rotation converged in 3 iterations.
Explained variance: 66.1%

Table A.4 Firms' benefits. Rotated Component Matrix

	R&D	Non-R&D based capabilities	Quality
Technology transfer	0.5232	0.5262	0.2061
Technology advice and consultancy to solve production problems	0.4561	0.5902	0.3561
To increase firms' absorptive capacities	0.4992	0.5118	0.3234
Information about technology forecast	0.3771	0.5854	0.3655
Hire human resources	0.4083	0.4965	0.2453
Joint R&D	0.7406	0.3844	0.253
Contract R&D	0.7358	0.3544	0.312
To use PRO facilities	0.7397	0.2812	0.3843
To perform test for products and process	0.572	0.2983	0.5781
Quality control	0.4619	0.3249	0.5595

Extraction Method: Principal Factors Analysis.
Rotation Method: Varimax with Kaiser Normalization.
Rotation converged in 3 iterations.
Explained variance: 62.2%

Table A.5 Researchers' benefits. Rotated Component Matrix

	Intellectual	Economic
Further collaboration projects	0.900	0.184
Ideas for further research	0.802	0.352
Knowledge/information sharing	0.754	0.324
Reputation	0.653	0.408
Share equipment/instruments	0.319	0.696
Provision of research inputs	0.320	0.803
Financial resources	0.216	0.797

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
Rotation converged in 3 iterations.
Explained variance: 69.8%

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