Channels of interaction between public research organisations and industry and benefits for both agents: evidence from Mexico

Gabriela Dutrénit[1], Claudia De Fuentes[2] and Arturo Torres[3]

Abstract

The process of knowledge transfer between Public Research Organizations and industry occurs through multiple channels of interaction, however there are differences in terms of the benefits that the agents perceive. Based on micro data, this paper explores which channels are the most effective for triggering different benefits perceived by researchers and firms involved in such interactions in Mexico. The results suggest that researchers obtain intellectual benefits from the Bi-directional and the Traditional channels. Firms obtain benefits related to production activities and innovation strategies from the Bi-directional and the Services channels, while the Traditional channel only provides production-related benefits. These results raise different policy issues. First, fostering the Bi-directional channel could contribute to building virtuous circles. Second, it is necessary to align the incentives to foster other channels of interaction. Third, a change of the researchers' incentives is required to induce new benefits coming from interactions.

Keywords: Public research organizations-industry interactions; channels of interaction; benefits; innovation policy; developing countries; Mexico

[1] Professor of the Master and PhD programs in Economics and Management of Innovation, Universidad Autónoma Metropolitana-Xochimilco, Mexico City, Calzada del Hueso 1100, col. Villa Quietud Coyoacán, CP 04960, Fax (5255) 5483 7235. gdutrenit@laneta.apc.org.

[2] Postdoctoral Fellow at the Master and PhD programs in Economics and Management of Innovation, Universidad Autónoma Metropolitana-Xochimilco, Mexico City, Calzada del Hueso 1100, col. Villa Quietud Coyoacán, CP 04960. Postdoctoral Fellow University of Ottawa, Faculty of Social Sciences, Department of Economics, 55 Laurier Avenue East, Desmarais Building, Ottawa, Ontario, Canada, K1N 6N5

[3] Professor of the Master and PhD programs in Economics and Management of Innovation, Universidad Autónoma Metropolitana-Xochimilco, Mexico City, Calzada del Hueso 1100, col. Villa Quietud Coyoacán, CP 04960.

1 Introduction[4]

It is broadly recognised that universities and public research centres, hereinafter public research organizations (PRO), are producers and transmitters of knowledge, and as such can make important contributions to improve firms' economic performance. In this sense, the role of PRO is evolving from human resources formation and knowledge generation to include a more oriented focus of problem-solving and contributing to development. In the case of developing countries, they can also promote economic and social development and contribute to meeting social needs (Arocena and Sutz, 2005).

PRO-industry (PRO-I) interactions may be one of the key elements of the National System of Innovation (NSI).[5] However, it is broadly recognised that PRO have evolved having limited linkages with firms in developing countries, which contributes to the weaknesses of their NSI (Cimoli 2000; Lall and Pietrobelli, 2002; Cassiolato, Lastres and Maciel, 2003; Muchie, Gammeltoft and Lundvall, 2003; Lorentzen 2009; Dutrénit et al, 2010). Stronger PRO-I interactions can play a role in consolidating NSI in developing countries, as they may promote virtuous circles in the production and diffusion of knowledge.

Empirical evidence suggests that the process of knowledge transfer between PRO and industry occurs through multiple channels. From the industry perspective, some authors argue that open science, patenting, human resources, joint R&D projects, and networking are the most important channels (Narin, et al, 1997; Swann, 2002; Cohen, Nelson and Walsh, 2002). From the academic perspective, Meyer-Krahmer and Schmoch (1998) found that joint R&D is the most important knowledge flow in some fields; D'Este and Patel (2007) highlight the importance of creation of new physical facilities, consultancy, contract and joint R&D, training, and meetings and conferences. According to Bekkers and Bodas Freitas (2008), the relative importance of the channels is similar amongst firms and academic researchers, however academic researchers assign more importance to the different channels than firms.

Referring to the benefits obtained through 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. Other benefits for researchers coming from collaboration generally speaking include testing applications of a theory and knowledge exchange, increasing contacts between researchers and firms, acquiring a new perspective to approach industry problems and the possibility of shaping the knowledge that is being produced at the academy, and securing funds for the laboratories and supplement funds for their own academic research (Meyer-Krahmer and Schmoch, 1998; Lee, 2000; Welsh et al, 2008). On the firms' side, Adams et al. (2003) and

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[5] 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; in the Mexican case researchers receive a set of common incentives that contribute to explaining how they tend to interact.

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. Rosenberg and Nelson (1994) argue that firms obtain a different perspective for the solution of problems and in some cases perform product or process innovations that without interaction would not have been possible; they also benefit from highly skilled research teams, new human resources, and access to different approaches for problem-solving. With a different focus, Bierly, Damanpour and Santoro (2009) emphasise the role of firms' absorptive capacities to explore external knowledge and of firms' financial leverage to exploit it.

However, less research has been done on the relative effectiveness of different channels of interaction on the benefits obtained by both agents. This paper focuses on this issue and, drawing on Arza (2010) in this Special Issue, assumes that benefits associated with PRO-I linkages are not the same across different channels of interactions. Some channels where knowledge flows in both directions involve intellectual resources and outputs by both PRO and industry, while others imply a unilateral provision of intellectual resources from PRO to firms. The use of different forms or channels may be associated with a set of motivations that lead them to interact.

Policymakers are keen to promote PRO-I interactions. However, they have hardly recognised that both agents respond to different incentives. In fact, PRO and firms interact for different reasons, have different preferred channels and obtain different benefits. In this sense, differences between both perspectives are important to understand the evolution of PRO-I interactions and promote specific policies to strengthen them.

Based on micro data of researchers and firms in Mexico, this paper explores what channels of interactions are the most effective for triggering different benefits for PRO and firms. We classify channels into four types according to the motivations to engage in linkages and the direction of knowledge flows; each channel includes a set of different forms of interaction: (i) Traditional channel relate to traditional ways of interaction (e.g. hiring graduates, conferences, publications), where knowledge flows mainly from PRO to firms, and its content is defined by conventional roles of PRO (e.g. teaching and researching); (ii) Services channel is motivated by the provision of scientific and technological services in exchange for money (e.g. consultancy, use of equipment for quality control, tests, training, etc.), knowledge flows mainly from PRO to firms; (iii) Commercial channel is encouraged by an attempt to commercialise scientific outcomes that PRO have already achieved (patents, technology licenses, incubators, etc.), knowledge flows mainly from PRO to firms; and (iv) Bi-directional channel is motivated by long-term targets of knowledge creation by PRO and innovation by firms (joint and contract R&D projects, participation in networks, etc.), knowledge flows in both directions and both agents provide knowledge resources.

We classify firms' benefits into two types: (i) Benefits related to short-term production activities (e.g. make earlier contact with university students for future recruiting, perform tests, help in quality control, etc.), and (ii) Benefits related to long-term innovation strategies (e.g. augment the firm's ability to find and absorb technological information, complementary and substitute research, etc.). Based on the nature of the benefits perceived by researchers, we distinguish: (i) Intellectual benefits, which are related to nurturing knowledge skills of PRO (obtain inspiration for future scientific research, ideas for new PRO-I collaboration projects, reputation, etc.), and (ii) Economic benefits, which are related to accessing to additional resources (provision of research inputs, financial resources, or share equipment/instruments).

Our argument is based on the idea that interactions may have more knowledge content, and thus more impact on researchers' and firms' benefits if a Bi-directional channel is used, and knowledge flows in both directions between the two agents. But each agent has specific motivations, which results in preferred channels that should be taken into account by policy makers. This conceptual framework is further developed in Arza (2010) in this Special issue.

This paper is part of an international comparative research on PRO-I interaction.[6] The cases of Argentina (Arza and Vazquez, 2010), Brazil (Fernandes et al, 2010) and Costa Rica (Orozco and Ruiz, 2010) presented in this Special Issue share the same conceptual framework and methodology.[7] This study is based on original data collected by two surveys carried out in Mexico during 2008, to firm's R&D and product development managers, and to academic researchers. We built two Heckman´s two-step estimation models, one for researchers and one for firms to identify the most important channels and other variables to benefit from interaction.

This paper is divided into five sections. Section 2 describes the context in which we analyse PRO-I interactions in Mexico; Section 3 describes the methodology and data gathering, and presents the Heckman model used to analyze the data; Section 4 contains the main findings and Section 5 concludes.

2 Roots of PRO-industry linkages in Mexico

The Mexican NSI is characterised by the absence of or by weak key actors, and by frail and irregular interactions among them (Cimoli, 2000; Dutrénit et al., 2010). The generation, dissemination and absorption rate of technological knowledge is low, and interactions are mainly restricted to PRO. The Mexican NSI shows a poor performance in terms of scientific and technological productivity, as illustrated by the participation in the worldwide publication of scientific papers (0.8% in 2007) and world patents submitted to the USPTO (0.06% in 2006). At the base of its fragility we found weak PRO-I linkages, which have evolved over time by the intervention of science, technology and innovation (STI) policies, institutions and other incentives.

Higher education in Mexico is rooted to 1910 with the creation of the National University of Mexico (UNAM). Other major public and private universities, such as the National Polytechnic Institute (IPN), the Technological Institute of Higher Studies of Monterrey (ITESM), the Metropolitan Autonomous University (UAM) and various state universities were established

[6] The international research project is titled "Interactions between universities and firms: searching for paths to support the changing role of universities in the South", developed under the umbrella of the Catching up project. It was sponsored by the IDRC (Canada). It compares PRO-Industry interactions of 12 countries from Latin America, Asia and Africa.
[7] Adeoti, Odekunle and Adeyinka (2010), Eom and Lee (2009), Eun (2009), Intarakumnerd and Schiller (2009), Joseph and Abraham (2009), Kruss (2009), Rasiah and Govindaraju (2009) discussed other results of this project.

between 1930 and 1980. The foundation of the IPN in 1936, strongly oriented to engineering and technological research, marked a fundamental turning point in the policies, which since then were oriented not only towards higher education but also to science and technology.

During 1930 and 1980, almost all public research centres were created, some of them linked to state firms and ministries (e.g. oil, agriculture, public health), and others oriented to three main scientific and technological areas - mathematics and natural sciences, social sciences and humanities, and innovation and technological development. Most of them were created from a supply-push perspective, without considering the demands of the productive sector, thus a mismatch between PRO's knowledge supply and firms' knowledge demand emerged from the origin.

The National Council on Science and Technology (CONACYT) was created in 1970 and became primarily responsible for STI policies. Like other agencies created in Latin America, it adopted a top-down approach, which has dominated the NSI scenery. The evolution of PRO was moulded by supply-push policies associated with the linear model of innovation, which was reinforced by CONACYT. PRO concentrate the greatest efforts in science and technology; four public institutions have been of remarkable importance: UNAM, IPN, UAM and the Centre for Research and Advanced Studies (CINVESTAV), which account for nearly 50% of scientific production in Mexico. Most of them are weakly connected to firms' demands.

Weaknesses in the linkages also emerge from the industry side. Private R&D expenditure has been weak over time and the productive sector has largely acted as an isolated actor within the NSI. There is a clear absence of regular linkages between firms and other economic and social actors, such as PRO. The origin of distortions inhibiting linkages with PRO is largely of economic nature. Firms within scarcely competitive markets would not be steered towards a strategy guided by innovation. A mismatch may also be related to practices of multinational corporations and large firms in mature sectors oriented to either look at production rather than to innovation, or to look for foreign knowledge suppliers. This and other market failures would be diminishing demand from knowledge provided by domestic PRO. As a result, the majority of interactions within the NSI have taken place in what may be denominated the public triad: CONACYT-public research centres-public universities.

Recognizing that knowledge generated in PRO plays an important role in driving firm level innovations, since early 1990s the Mexican government implemented explicit policies to stimulate PRO-I linkages. They were strengthened at the end of the 1990s, with the approval of the Science and Technology Laws in 1999 and 2002, and the Special Program for Science and Technology 2001-2006 (PECYT). Recent STI programmes try to switch from a top-down to a bottom-up system of incentives. Until 2009 the main programs fostering PRO-I interaction in terms of resources were the R&D fiscal incentives and the Sectoral fund for innovation.

As the society and the economic system rapidly advance toward a more intensive production and exploitation of all types of knowledge, PRO-I linkages have drawn attention as one of the central factors underlying the innovative process dynamic. However, only few studies have analyzed PRO-I interactions in Mexico, most of them based on case studies for specific sectors (Casas, 2001) or centred on the academic capacities of PRO (Casas and Luna, 1997). As far as we know, there is no study on the benefits that these two agents could derive from different channels of interaction. This study aims to contribute to the understanding of the relationships between these factors.

3 Research design and descriptive statistics

3.1 *Data collection and sample characteristics*

This study is based on original data collected by two surveys on PRO-I interactions carried out in Mexico during 2008. Firms' survey was answered by R&D and product development managers. 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. Academics' survey was answered by researchers working at PRO. This survey includes: researcher's and team's characteristics, forms of PRO-I interaction, and personal and institutional benefits from interaction.

The sampling frame was constructed from the National Researchers System (NRS) database.[8] 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 that are quite active in applying for public grants. We complemented this 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). 71% of researchers belong to a research group, and 61% of the research groups have links with firms. 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 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

[8] This 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.

from all manufacturing sectors, non-innovative were excluded. 67% are R&D performers, 42% have 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 access to public funds to foster R&D, thus they may perform R&D activities.

3.2 *Construction of variables*

The key variables are channels of interaction and benefits from interaction. We follow a categorization based on the theoretical framework, summarised in Section 1, to allow comparison between countries (see Arza, 2010 in this issue for further explanation). To build the variable of Channels we rely on a question where researchers and firms evaluated the importance of each form of interaction. Thus, forms of interaction were classified in 4 channels according to the motivations to engage in linkages and the direction of knowledge flows. We built each channel from the simple average of the forms of interaction that integrated it (Table 1).

Table 1 Channels of PRO-industry interaction

Forms	Channels
Networking with firms Joint R&D projects Research contract	Bi-directional (BCh)
Patents Technology licenses Incubators Spin-off from PRO	Commercial (CCh)
Staff mobility Consultancy and technical assistance Informal information exchange Training staff	Services (SCh)

Forms	Channels
Conferences and expos Publications Graduates employed recently in the industry	Traditional (TCh)

Notes: We used a likert scale from 1-4, which was standardized to 0.25 to 1. Industrial parks and internships were not included in this analysis as they show a high number of missing values.

We built different types of benefits for researchers and firms; we followed the same ad-hoc characterization as other countries in this Special Issue. Firms' benefits are defined as those related to long-term innovation strategies (In) and those related to short-term production activities (P) (Table 2). To build this variable we rely on a question where firms evaluated the importance of achieving specific objectives from their interaction with PRO, but we only considered the cases where firms evaluated as positive the results from interaction. We calculated the simple average from the responses that integrate each benefit.

Table 2 Type of benefits for firms

Benefits related to long-term innovation strategies	Technology transfer from the university
	Augment firm's ability to find and absorb technological information
	Get information about trends in R&D in the field
	Contract research to contribute to the firms' innovative activities
	Contract research that the firms do not perform
Benefits related to short-term production activities	Obtain technological/consulting advice to solve production problems
	Make earlier contact with university students for future recruiting
	Use resources available at PRO
	Perform test for products/processes
	Help in quality control

Note: We used a likert scale from 1-4, which was standardized to 0.25 to 1.

To build the variable of researchers' benefits we rely on a question where researchers evaluated the importance of benefits during their interaction with firms. In this case, we performed a factor analysis and grouped the benefits into two factors, which refer to Economic (E) and Intellectual (I) benefits (Table 3), we used the factor loadings from the factor analysis.[9] This classification is similar to that proposed by Arza (2010) in this Special Issue.

Table 3 Type of benefits for researchers

Economic benefits	Share equipment / instruments
	Provision of research inputs
	Financial resources
Intellectual benefits	Ideas for further collaboration projects
	Inspiration for further scientific research
	Share of knowledge/information
	Reputation

[9] Table A.1 in the Annex presents the rotated matrix for benefits.

Even though other methodological approaches could have been used for building the variables of benefits and channels, these constructs prioritize comparability between countries in this Special Issue.

Other independent variables for researchers and firms used in the model are associated with the probability of linking and the determinants of benefits from interaction. For researchers we analyzed knowledge skills, academic collaboration, networking with firms and institutional affiliation (Table 4).

Table 4 Variables for analysing PRO-I linkages from the researchers' perspective

Characteristic	Variable	Type of variable
Knowledge skills	Degree	Dummy: PhD=1; Master=1; Graduate=0
	Type of research	Dummy: Basic science=1; Technology development=1; Applied science=0
	Research field	Dummy: Physic & Mathematics=0; Chemistry & Biology=1; Medicine & Health Sciences=1; Biotechnology & Agronomy=1; Engineering=1
Academic collaboration	Member of a research team	Dummy: Yes=1; No=0
	Human resources in the team	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, College researchers and technicians=0.1
	Team age	Numerical
Networking with firms	Importance of linking with firms	Dummy: Yes=1 (highly important); No=0 (without importance)
	Initiative of collaboration	Dummy: Firms' initiative=1; Both=1; Researchers' initiative=0
Institutional affiliation	Type of organization	Dummy: 1=University, 0=Public research centres
Channels of interaction	Bi-directional Traditional Services Commercial	Index 0.25-1 to measure the importance of each form of interaction
Benefits	Intellectual Economic	Factor loads from factor analysis

For firms we analyzed variables related to innovative capabilities, firms' characteristics, strategy, and the role they perceive for PRO (Table 5). Regarding strategy, one of the variables we analyzed was openness strategy. We draw on Laursen and Salter (2004)[10] to build 4 factors by

[10] 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.

principal components that express the firm's openness strategy to obtaining information from external sources.[11]

Table 5 Variables for analyzing PRO-industry linkages from the firms' perspective

Characteristic	Variable	Type of variable
Innovative capabilities	Human resources in R&D	Numerical: Human resources in R&D as % of the total employment
	Formalization of R&D and innovation activities	Dummy: Formal and continuous innovative activities=1; Otherwise=0
Firms' characteristics	Firm size	Numerical: ln of firms' employees
	Technology sector	Categorical: 0.25: low; 0.5: medium-low; 0.75: medium-high; 1: high
	Ownership	Dummy: Foreign investment=1; Otherwise=0
Strategy	Openness strategy F1-F4	Factor loads from factor analysis of external sources of information for: F1=Access to open information, F2=Consulting and research projects with other firms, F3=Market, F4=Suppliers.
	Fiscal incentives for R&D	Dummy: Yes=1; No=0
Role of PRO	Creation and transfer of knowledge	Categorical: 0.25: without importance; 0.5: low importance; 0.75: medium importance; 1: high importance.
Channels of interaction	Bi-directional Traditional Services Commercial	Index 0.25-1 to measure the importance of each form of interaction
Benefits	Related to long-term innovation strategies Related to short-term production activities	Index 0.25-1 to measure the importance of each individual benefit

3.3 *The model and estimation procedures*

This paper built a Heckman´s two-step estimation model (Heckman, 1978), which helps to isolate the factors that affect the selection process and reduce the selection bias to identify the determinants of the final dependent variable. The first stage is a selection equation that estimates the probability of linking for researchers and firms. In this stage, a Probit regression is computed, the dependent variable (d_V_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 (RV_i) and firms (FV_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 (see equations 1.1, 1.3, 2.1 and 2.3 below).

[11] The common explained variance by these factors is 66.1%. See Table A.2 in the Annex for a better description of the factor analysis.

The second stage estimates the main determinants of benefits from interaction. In this stage, a linear regression is computed. The dependent variable (Benefits) is a *pseudo-continuous* variable that expresses the importance of benefits from interaction. We conceptualized one equation for each type of benefit for researchers and firms. The vectors of independent variables are those features of researchers and firms that determine the benefits from interaction. The critical independent variables are channels of interaction (Ch_i). From the questionnaire design, we can assume causality between channels of interaction and benefit for researchers; in contrast, both directionalities could be assumed for the case of firms. So we rely on the conceptual framework described in Section 1 to explain causality in this case; different channels have the potential to trigger different kinds of benefits for researchers (Intellectual-IB_i and Economic-EB_i) and for firms (related to short-term production activities–PB_i and to long-term innovation strategies-InB_i). However, there are other researchers' and firms' features (Ri and F_i respectively) that may determine the benefits from interaction (see equations 1.2, 1.4, 2.2 and 2.4 below).

We follow two sets of equations, one for researchers and another for firms.

a) Researchers´ perspective:

(1.1) $d\_V = RV_i\beta + u_i$

(1.2) $IB_i = Ch_i\alpha + R_i\delta + \varepsilon_i$

(1.3) $d\_V = RV_i\beta + u_i$

(1.4) $EB_i = Ch_i\alpha + R_i\delta + \varepsilon_i$

RV_i: *Degree, type of research, research field, member of a research team, importance of linking with firms, and type of organization*.

R_i: *Degree, research field, human resources in the team, team age, initiative of collaboration, type of organization.*

IB: *Intellectual benefits.*

EB: *Economic benefits.*

b) Firms´ perspective:

(2.1) $d\_V = FV_i\beta + u_i$

(2.2) $PB_i = Ch_i\alpha + F_i\delta + \varepsilon_i$

(2.3) $d\_V = FV_i\beta + u_i$

(2.4) $InB_i = Ch_i\alpha + F_i\delta + \varepsilon_i$

FV_i: *Formalization of R&D and innovation activities, firm size, technology sector, ownership, openness strategy, fiscal incentives for R&D, and creation and transfer of knowledge.*

F_i: *Human resources in R&D, formalization of R&D and innovation activities, firm size, technology sector, ownership, openness strategy, and fiscal incentives for R&D.*

PB: *Benefits related to short-term production activities.*

InB: Benefits related to long-term innovation strategies.

We first chose the variables of the selection model that may affect the probability of linking. Secondly, we identified the best possible model for the selection equation by estimating different specifications of Probit models on the probability of linking. To select the variables that better fit the model we performed a log-likelihood ratio test (LR) on the Probit models. Thirdly, we selected the variables that better describe the benefits from PRO-I interaction and tested them on the overall Heckman model.

3.4 *Descriptive statistics: channels and benefits*

Concerning channels of interaction, Table 6 shows the average of importance and the percentage of higher importance for each form and channel of interaction for researchers and firms. Researchers and firms have different perceptions regarding the importance of channels. Researchers value more the Bi-directional channel (60%), particularly knowledge transfer through joint research. Firms value more the Traditional channel (58%). This suggests that from firms´ perception, PRO above all contribute with human resources creation and knowledge diffusion, while for the researchers' perspective, the generation of knowledge has a crucial role. The Commercial channel is the least important for both agents.

Table 6 Importance of Channels and forms of PRO-I interaction

Channels and Forms of interaction	Researchers' perspective		Firms' perspective	
	Average	% of researchers for whom it is important	Average	% of firms for whom it is important
Traditional (TCh)	**0.54**	**37.7**	**0.58**	**47.7**
Publications	0.50	30.1	0.59	45.3
Conferences and expos	0.61	48.6	0.58	48.9
Graduates employed recently in the industry	0.53	34.3	0.57	48.9
Services (SCh)	**0.58**	**47.3**	**0.54**	**40.0**
Consultancy and technical assistance	0.60	50.1	0.54	40.3
Staff mobility	0.48	32.7	0.45	25.2
Informal information exchange	0.65	57.7	0.56	41.9
Training staff	0.59	48.8	0.61	52.6
Bi-directional (BCh)	**0.60**	**49.0**	**0.54**	**39.6**
Research contract	0.64	55.3	0.54	37.8
Joint R&D projects	0.68	61.0	0.58	46.5
Networking with firms	0.58	47.0	0.49	34.5
Commercial (CCh)	**0.48**	**30.3**	**0.43**	**24.8**
Spin-off from PRO	0.45	25.7	0.34	10.8
Incubators	0.51	35.1	0.44	24.3
Technology licenses	0.47	29.9	0.48	30.8
Patents	0.48	30.6	0.49	33.5

Regarding benefits, researchers rank higher Intellectual benefits (69%) than Economic benefits (56%). This result suggests that researchers are knowledge driven rather than economic driven. The most important individual benefits are related to new collaboration projects and new scientific research. In the case of firms, benefits related to short-term production activities (42%) are more important than benefits related to long-term innovation strategies (39%). The most important individual benefit is associated with contacting students for future recruiting, which is related to short-term production activities. Regarding benefits related to long-term innovation strategies, the most important is associated with absorbing technological information, which does not imply an active participation of the firm in the knowledge generation process.

4 Main findings

4.1 *Estimation of Heckman models I: researchers' data*

Table 7 presents the results of the Heckman model for equations (1.1) and (1.2) for intellectual benefits and (1.3) and (1.4) for economic benefits.

Table 7 Heckman estimates of economic and intellectual benefits for researchers

	Selection (1.1)	Intellectual Benefits (1.2)	Selection (1.3)	Economic Benefit (1.4)
Master	-0.6401** (0.3162)	0.5444* (0.3192)	-0.7716** (0.3109)	-0.2689 (0.3592)
PhD	-1.2633*** (0.2603)	0.6630*** (0.2310)	-0.9215*** (0.2360)	0.0571 (0.2706)
Chemistry & Biology	0.1999 (0.1812)	-0.1885 (0.2664)	0.2099 (0.1919)	0.0776 (0.2294)
Medicine & Health Sciences	-0.6124** (0.2921)	-0.1942 (0.4322)	-0.3529 (0.2612)	0.1564 (0.3800)
Biotechnology & Agronomy	1.1861*** (0.1800)	-0.2436 (0.2244)	1.0305*** (0.2014)	-0.1869 (0.2246)
Engineering	0.4770*** (0.1653)	-0.3317 (0.2260)	0.5216*** (0.1629)	-0.2156 (0.2079)
Basic science	0.5543*** (0.1379)		0.4924** (0.2108)	
Technology development	0.8822*** (0.1682)		0.6772** (0.3355)	
Member of a research team	0.4668*** (0.1376)		-0.0539 (0.2041)	
Team age		-0.0087* (0.0053)		0.0116** (0.0058)
Human resources in the team		0.0062* (0.0029)		-0.0081** (0.0030)
Type of organization	-0.5716*** (0.1240)	0.1366 (0.1181)	-0.4057*** (0.1166)	0.0838 (0.1345)

	Selection (1.1)	Intellectual Benefits (1.2)	Selection (1.3)	Economic Benefit (1.4)
Importance of linking with firms	1.6300*** (0.1131)		1.5660*** (0.0981)	
Firms initiative of collaboration		-0.2751* (0.1593)		0.1713 (0.1967)
Both initiative of collaboration		-0.2182 (0.1175)		0.0623 (0.1273)
Traditional channel		0.8433* (0.4501)		0.1534 (0.3618)
Bi-directional channel		0.7082** (0.3578)		0.1725 (0.3501)
Services channel		0.4699 (0.3798)		0.1718 (0.4211)
Commercial channel		-1.0629*** (0.3180)		0.0039 (0.3274)
_cons	-0.0382 (0.3067)	-0.6854* (0.3547)	0.0152 (0.4724)	0.0173 (0.4196)
Observations		382		382
Censored		150		150
Wald Chi2(15)		58.61		36.70
Prob>chi2		0.0000		0.0014
athrho		-0.8511***		-1.5601
lnsigma		-0.0807		0.0473
Wald test of indep. eqns. (rho = 0): chi2(1) =		37.48		11.31
rho		-0.6916		-0.9154
sigma		0.9225		1.0485
lambda		-0.6380		-0.9598

Note: *p ‹ 0.1; **p ‹ 0.05; ***p ‹ 0.005
Results from the selection equations (1.1 and 1.3) are fairly similar, which increases the robustness of our model.

Equations 1.2 and 1.4 show the results of the specific channels and other factors that determine the benefits obtained by researchers from interaction with industry. There is a significant and positive relationship between the Bi-directional and Traditional channels, and the Intellectual benefits, which is more significant for the former. In contrast, even though several authors recognise the importance of Economic benefits for PRO (Geuna, 2001; Lee, 2000; Meyer-Krahmer and Schmoch, 1998), none of the four channels contribute to receiving economic benefits. The Bi-directional channel includes interaction through joint and contract R&D projects; this involves a higher level of interdependency between both agents than other channels, bringing the possibility of solving more complex problems and contributing to knowledge generation (Perkmann and Walsh, 2009). Forms of interaction included in the Traditional channel do not require formal linkages, and, as asserted by D'Este and Patel (2007), tacit and codified knowledge flow from these types of interaction. The importance of both channels suggests that Mexican researchers receive intellectual benefits through formal and informal channels. It is worth noting that in spite of the researchers' perception about benefits coming from the Bi-directional channel, as pointed out by Perkmann and Walsh (2009), whether researchers can capitalize or not the benefits from this interaction depends on having a strong focus on research.

On the contrary, we found a significant, negative and high coefficient of the Commercial channel. If we look at the case of patents and technology licenses included here, they have a double face, on one side, they protect the knowledge generated through interaction and, on the other, they are a way to diffuse it with some lag. The negative relationship suggests that for the Mexican researchers the restriction on knowledge sharing is more important than the possibility of using this knowledge for future research. This form of interaction is not the most common during PRO-I interaction (Cohen, Nelson and Walsh, 2002; D'Este and Patel, 2007), however it resulted quite important in the case of Korea (Eon and Lee, 2009). In any case, this negative impact on benefits does not seem to be a common feature in developed countries either.

Regarding other factors that affect the benefits from interaction, we found a positive relationship between holding a Master's or a PhD degree and obtaining intellectual benefits, the significance is very high in the case of PhD. Even though having a Master's or a PhD negatively relates to the likelihood of connecting, once researchers are linked, they can get more intellectual benefits if they have a postgraduate degree. Referring to academic collaboration, we found different impacts on benefits. On one side, working in a more robust research team (with more qualified human resources) makes it possible to obtain more intellectual benefits than working individually, which suggests that interaction in this context leads to higher levels of discussion and ideas generation. In contrast, researchers obtain less economic benefits, as resources have to be distributed within a larger number of researchers. On the other, as the team is more experienced (in terms of years), researchers can obtain more economic benefits. This suggests that as research groups become consolidated, members of the team learn how to establish and manage collaborative projects, generating routines that allow them to get more economic benefits. In contrast, experience of the team does not contribute to obtain more intellectual benefits, which suggests that routinization does not contribute to the flourishing of ideas. Whoever takes the initiative to collaborate has also important impacts on benefits; as the University takes the initiative, it is more likely that researchers will obtain intellectual benefits than if the initiative comes from the firms.

Even though this paper focuses on the relationship between channels and benefits, from the selection equations (1.1) and (1.3), we can learn that according to the researchers' perspective the main drivers for interaction are associated with three type of factors: (i) knowledge skills: researchers' degree, research field and type of research; (ii) academic collaboration: member of a research team; and (iii) institutional affiliation: type of organization –public research centre or university. Researchers without postgraduate degree, members of a team, and those working in a public research centre are more likely to connect with industry than otherwise. Concerning the research fields, the results confirm that there are significant differences between fields as referred to the likelihood of connecting. Researchers from Biotechnology & Agronomy and Engineering tend to connect more with industry than researchers from Physics & Maths, as was expected. However, Medicine & Health Sciences tend to connect less than Physics & Maths. Regarding the type of research, researchers that carry out basic science and technological development tend to connect more than those that carry out applied research. These results require further research and go beyond the scope of this paper.

4.2 *Estimation of Heckman models II: firms' data*

Table 8 presents the results of the Heckman model for equations (2.1) and (2.2) for benefits related to short-term production activities and (2.3) and (2.4) for benefits related to long-term innovation strategies.

Table 8 Heckman estimates of production and innovation benefits for firms

	Selection (2.1)	Production related Benefits (2.2)	Selection (2.3)	Innovation related Benefits (2.4)
Human resources in R&D		0.0022** (0.0009)		0.0025** (0.0010)
Formalization of R&D and innovation activities	-0.02810 (.3025)	0.1071** (0.0531)	-0.1225 (0.3441)	0.0785 (0.0578)
Firm size	-0.0022 (0.0651)	-0.0022 (0.0081)	0.0198 (0.0603)	-0.0044 (0.0088)
Technology sector	0.2237 (0.3555)	-0.0520 (0.0508)	0.3484 (0.3581)	-0.0314 (0.0506)
Ownership	0.0603 (0.1897)	-0.0355 (0.0281)	0.0412 (0.2022)	0.0113 (0.0307)
Openness strategy F1 (open information)	0.2323*** (0.0870)	-0.0391*** (0.0145)	0.2265** (0.0974)	-0.0074 (0.0155)
Openness strategy F2 (consulting and research projects with other firms)	0.1400 (0.0956)	0.0186 (0.0135)	0.1977** (0.0934)	0.0337** (0.0164)
Openness strategy F3 (customers and competitors)	0.0054 (0.0844)	-0.0150 (0.0129)	0.0448 (0.0825)	-0.0186 (0.0123)
Openness strategy F4 (suppliers)	0.2066** (0.0933)	-0.0086 (0.0140)	0.2145** (0.0888)	-0.0111 (0.0151)
Fiscal incentives for R&D	0.5060** (0.1977)	-0.0643** (0.0301)	0.3832** (0.1887)	-0.0570* (0.0336)
Creation and transfer of knowledge	1.1623*** (0.3024)		1.1459*** (0.3368)	
Traditional channel		0.1330* (0.0731)		0.0146 (0.0706)
Bi-directional channel		0.2303** (0.0892)		0.2049** (0.0957)
Services channel		0.1839* (0.0963)		0.1986* (0.1029)
Commercial channel		-0.0243 (0.0949)		0.0585 (0.1142)
_cons	-0.3876 (0.4970)	0.2949 (0.0736)	-0.4141 (0.5871)	0.2637 (0.0892)
Observations		310		310
Censored obs		69		69
Wald Chi2(14)		174.74		109.51
Prob>chi2		0.000		0.000
athrho		-1.0954		-0.6492
lnsigma		-1.5909		-1.6105
Wald test of indep. eqns. (rho = 0): chi2(1) =		12.38		2.03
rho		-0.799		-0.571
sigma		0.204		0.200
lambda		-0.163		-0.114

Note: *p ‹ 0.1; **p ‹ 0.05; ***p ‹ 0.005

Results from the selection equations (2.1 and 2.3) are fairly similar, which increases the robustness of our model.

Equations 2.2 and 2.4 show the channels and other factors that contribute to obtaining benefits by firms from interaction. Except for the Commercial, all the channels have a positive and significant relationship with short-term production related benefits. The Bi-directional and Services channels have a positive and significant relationship with long-term innovation related benefits. The positive and strong effect of the Bi-directional channel on both benefits suggest that firms engaging with PRO through formal interactions, such as joint and contract R&D projects, get more significant benefits. Along the same lines, Arvanitis, Sydow and Woerter (2008) found that interaction through R&D has a positive effect on innovation and productivity. The positive effect of the Services channel on both benefits is also consistent with some of their results, as they found that investment in employees associated with training has a positive impact on innovation and productivity. The Traditional channel only has a positive impact on production related benefits, which suggests that more informal type of interactions bring short-term related benefits.

Regarding other factors that have an impact on benefits from interaction, we found that firms' innovation capabilities are important in obtaining both production and innovation related benefits from interaction; human resources in R&D have a positive effect on both types of benefits while the formalization of R&D activities is more important for short-term production solutions than for long-term innovation strategies. The impact of the former is consistent with the findings by Bierly, Damanpour and Santoro (2009), which argued that benefits in terms of exploration or exploitation activities depend on firm's ability to innovate. In contrast, the latter suggests that formalization of R&D and innovation activities by Mexican firms is more related to solving production problems than to innovating.

We found that firm´s openness strategy based on consultancy and research projects with other firms allows them to get more long-term innovation benefits from interactions with PRO. This result is consistent with previous findings by Rosenberg and Nelson (1994). On the other hand, we found a negative relationship between the production related benefits that a firm could obtain and a strategy based on access to open information. It might be that as firms increasingly gain access to publications, technical reports and other open sources, they gradually develop capabilities to solve short-term production problems, previously solved with the help of PRO, or they find other external sources of knowledge to solve their production problems.

Although fiscal incentives for R&D are a driver of linkages with PRO, they are negatively related to both types of benefits. These apparently contradictory results bring attention on discussing the role of this policy instrument to foster linkages. Originally designed to boost R&D activities amongst firms, their engagement with knowledge producers -such as PRO- was not a direct aim of this instrument, but a tangential effect. Having connections with PRO increased the firms' chances of being selected as tax credit beneficiaries, thus it might be that some firms engaged in linkages to gain access to R&D subsidies. Thus these firms may not consciously look for benefits derived from those interactions, which can explain these results.

Equations (2.1) and (2.3) suggest that the main drivers for interaction according to the firms' perspective are associated with two factors: (i) firms' strategy: openness strategy and fiscal incentives for R&D; and (ii) the role of PRO in relation to the creation and transfer of knowledge. Our results confirm findings by Laursen and Salter (2004) that firms that deliberately search for external knowledge sources are more likely to establish linkages with PRO than those that do not follow such an openness strategy. In our case, strategies based on access to open information, consulting and research projects with other firms, and interaction with suppliers are more important drivers for interaction than those based on customers and competitors. Firms accessing fiscal incentives for R&D and firms attaching an important role to PRO for the creation and transfer of knowledge tend to connect more with PRO than otherwise. These results bring some specificities of the Mexican case and deserve more analysis, however drivers of PRO-I are not the main focus of this paper.[12]

5 Conclusions

Our findings show that in the Mexican case both agents use a variety of channels. This study provides additional support to previous analyses which found that human resources formation, the creation of new physical facilities, consultancy, contract and joint research, training, meetings and conferences are more important forms of interaction than patenting and spin-offs (Cohen, Nelson and Walsh, 2002; D'Este and Patel, 2007).

Instead of the similar relative importance assigned by firms and researchers to the different channels, as argued by Bekkers and Bodas Freitas (2008), we found that agents have different perceptions on the importance of the channels. Based on the assumption that there is causality between channels and benefits,[13] we argue that benefits associated with PRO-I linkages for both agents are not the same across different forms/channels of interactions. Mexican researchers value more the Bi-directional and the Traditional channels only for intellectual benefits, while firms attach value to the Bi-directional and the Services channels for innovation related benefits and these and the Traditional channel for production related benefits. The Bi-directional channel brings benefits for both agents and is associated with knowledge flows in both directions; it may contribute to a higher interdependence between PRO and firms. As pointed out by Adams et al. (2003), dual benefits could contribute to building virtuous circles for PRO-I interaction.

Our findings suggest that researchers are knowledge driven rather than economic driven, as they value more the impacts of interaction on intellectual than on economic benefits. In the case of firms, they tend to connect to domestic PRO to get both short-term problem solving and insights for long-term innovative strategies. The importance of the Bi-directional channel supports the emphasis put by authors based on evidence from developed countries on forms of interaction related to knowledge creation (Rosenberg and Nelson, 1994; D'Este and Patel, 2007; Perkmann and Walsh, 2009). However, the importance of benefits coming from other channels (Traditional and Services) suggests that in our case it is necessary to open the analysis to other forms of interaction different from joint or contract research to induce knowledge transfer and foster innovation.

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[12] See Torres et al (2009) for the analyses of the drivers in the Mexican case.

[13] As discussed in section 3.3, we can affirm that this causality actually exists for the case of researchers; while for the case of firms we rely on the theory to support this argument.

According to the analysis, the Commercial channel brings negative effects on intellectual benefits for researchers, and does not have any effect on firms' benefits. This result can be related to the fact that the forms of interaction included in this Channel –patents, technology licenses, spin-offs and incubators- are not very common on the Mexican case, and the effort to link through these forms of interaction are much higher that the benefits obtained from them. This suggests that recent innovation policy efforts to foster commercialization of research neglect the perception of both agents and are likely to fail.

Our findings have some other policy implications. The importance of the graduates recently hired from the firms' perspective suggests that they could be seen as an important interface between researchers and firms. This calls for new policies oriented to working with undergraduates to foster interactions and innovation by the firms once they are hired, or to promoting networks between firms and PRO through graduates' mobility, as argued by Wright et al. (2008). As the Traditional and the Services channels imply unilateral provision of intellectual resources and outputs from PRO, and researchers do not obtain benefits from them, it is necessary to foster changes in the researchers' motivations and perceptions. Thus policies may introduce new programs that induce a more active participation of firms in the knowledge flows associated with these channels/forms of interactions, so researchers may be more motivated, or change the incentives and forms of evaluation of researchers so that these interactions may generate some kind of benefits.

The significance of the drivers related to perceptions about the partner, both from the firms' and the researcher's perspective, suggest that working on the agents perceptions may have an impact on the performance of PRO-I linkages. However, mismatches between PRO's knowledge supply and firms' knowledge demand are driven by market failures. The origin of the distortions inhibiting innovation is largely of an economic nature. Thus, obstacles for PRO-I interactions lie also in the fact that the most profitable activities in the Mexican market seem to have no relation to innovation efforts; in other words, signals of relative profit in the short-term seem to be distorted against innovation. This suggests that policymakers should give serious consideration to the weaknesses of PRO-I links derived from the lack of competition in different sectors and markets. Policymakers should be attentive also to possible tangential effects derived from policies not directly designed to encourage PRO-I interactions. An example of this is the programme on Fiscal Incentives for R&D, an instrument that has had impacts on fostering PRO-I interactions, but not yet the benefits obtained from these interactions. Learning through interaction may have been a by-product of this program, showing the potential benefits they could obtain from that relationship. By now, policy instruments like this may help to overcome barriers for interaction, but the analysis of those impacts requires further investigation.

Finally, policymakers concerned with fostering PRO-I linkages should also put emphasis on promoting activities related to 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.

Annex

Table A.1 Researchers' benefits. Rotated Component Matrix

	Intellectual benefits	Economic benefits
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: 69.89%

Table A.2 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%

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