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Channels of interaction between public research organisations and industry and their benefits: evidence from Mexico

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The process of knowledge transfer between public research organisations 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. Secondly, it is necessary to align the incentives to foster other channels of interaction. Thirdly, a change in the researchers' incentives is required to induce new benefits from interactions.

IT IS BROADLY RECOGNISED that universities and public research centres (hereinafter public research organisations (PROs)) are producers and transmitters of knowledge, and as such can make important contributions to improve firms' economic performance. In this sense, the role of PROs is evolving from human resources formation and knowledge generation to include a more oriented focus on 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).[1] However, it is broadly recognised that PROs 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 *et al*., 2003; Muchie *et al*., 2003; Lorentzen 2009; Dutrénit *et al*., 2010). Stronger PRO-I interactions can play a role in consolidating NSIs 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 research and development (R&D) projects, and networking are the most important channels (Narin *et al*., 1997; Swann, 2002; Cohen *et al*., 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 creating new physical facilities, consultancy, contract and joint R&D, training, meetings and conferences. According to

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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 do firms.

Referring to the benefits obtained through interaction, most of the authors have analysed 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 the researchers make efforts to exploit collaboration for research purposes. In general, other benefits from collaboration for researchers include: testing applications of a theory and knowledge exchange, increasing contacts between researchers and firms, acquiring a new perspective from which to approach industrial problems and the possibility of shaping the knowledge that is being produced at the academy, and securing funds for the laboratories and supplementary funding 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 Arvanitis *et al*. (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 solving problems and in some cases perform product or process innovations that would not have been possible without the interaction. They also benefit from highly skilled research teams, new human resources, and access to different approaches for problem-solving. With a different focus, Bierly *et al*. (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 the paper by Arza (pp 473–484, this issue), assumes that benefits associated with PRO-I linkages are not the same across different channels of interaction. Some channels where knowledge flows in both directions involve intellectual resources and outputs by both PROs and industry, while others imply a unilateral provision of intellectual resources from PROs to firms. The use of different forms or channels may be associated with a set of motivations that lead them to interact.

Policy-makers are keen to promote PRO-I interactions. However, they have barely recognised that the agents respond to different incentives. In fact, PROs and firms interact for different reasons, have different preferred channels and obtain different benefits. In this sense, the differences between their perspectives are important for understanding the evolution of PRO-I interactions and promoting specific policies to strengthen them.

Based on micro-data of researchers and firms in Mexico, this paper explores which channels of interactions are the most effective for triggering different benefits for PROs 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:

- The traditional channel relates to traditional ways of interaction (e.g. hiring graduates, conferences and publications), where knowledge flows mainly from PROs to firms, and its content is defined by the conventional roles of PROs (e.g. teaching and researching).
- The 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.
- The commercial channel is encouraged by an attempt to commercialise scientific outcomes that PROs have already achieved (patents, technology licenses, incubators etc.), knowledge flows mainly from PROs to firms.

- The bi-directional channel is motivated by long-term targets of knowledge creation by PROs 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:

- Benefits related to short-term production activities (e.g. make earlier contact with university students for future recruitment, perform tests, help in quality control, etc.).
- 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:

- 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.).
- Economic benefits, which are related to accessing 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 by Arza (pp 473–484) in this special issue.

This paper is part of an international comparative research project on PRO-I interaction.[2] The cases of Argentina (Arza and Vazquez, pp 499–511), Brazil (Fernandes *et al*., pp 485–498) and Costa Rica (Orozco and Ruiz, pp 527–540) presented in this special issue share the same conceptual framework and methodology.[3] This study is based on original data collected by two surveys carried out in Mexico during 2008, in which questionnaires were sent to firm's R&D and product development managers, and to academic researchers. We built two Heckman 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. The second section describes the context in which we analyse PRO-I interactions in Mexico; the third section describes the methodology and data gathering, and presents the Heckman model used to analyse the data; the fourth section contains the main findings, conclusions are then drawn.

Roots of PRO-I linkages in Mexico

The Mexican NSI is characterised by weak, or absent, key actors, and by frail and irregular interactions between them (Cimoli, 2000; Dutrénit *et al*., 2010). The generation, dissemination and absorption rate of technological knowledge is low, and interactions are mainly restricted to PROs. 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 US Patent and Trademark Office (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 goes back 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 in the period 1930–1980. The foundation of the IPN in 1936, strongly oriented toward engineering and technological research, marked a fundamental turning point in policies, which have since been oriented not only towards higher education but also to science and technology.

During the period 1930–1980, almost all the public research centres were created, some of them linked to state firms and ministries (e.g. oil, agriculture and 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 PROs' knowledge supply and firms' knowledge demand emerged from their 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 landscape. The evolution of PRO was moulded by supply-push policies associated with the linear model of innovation, which was reinforced by CONACYT. PROs concentrate their 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 the demands of the firms.

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 PROs. These distortions which inhibit linkages with PROs are largely economic in nature. Firms within scarcely competitive markets would not be steered towards a strategy guided by innovation. A mismatch may also be related to the practices of multinational corporations and large firms in mature sectors, who are inclined to either look at production rather than to innovation, or to look for foreign knowledge suppliers. This and other market failures would diminish demand for knowledge provided by domestic PROs. As a result, the majority of interactions within the NSI have taken place in what may be termed the public triad: CONACYT–public research centres–public universities.

Recognising that knowledge generated in PROs plays an important role in driving innovations in firms, since the early 1990s the Mexican government has implemented explicit policies to stimulate PRO-I linkages. These were strengthened at the end of the 1990s, with the passing 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 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 a few studies have analysed PRO-I interactions in Mexico, most of them based on case studies for specific sectors (Casas, 2001) or centred on the academic capacities of PROs (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.

Research design and descriptive statistics

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. The firms' survey was answered by R&D and product development managers. It included questions about: innovation and R&D activities, sources of knowledge and forms of PRO-I interaction, objectives and benefits from interaction, and perceptions about the main role of PROs. The academics' survey was answered by researchers working at PROs. This survey included: 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.[4] 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 the engineering departments of the main PROs to include researchers who are not part of the NRS but tend to have linkages with firms. Finally the response rate was 14%. For this paper, the sample comprised 385 researchers belonging to PROs, 81% of them belong to the NRS, and 61% have links with 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% have a Master's degree and 6% are graduates. In terms of the institutional affiliation, 58% of the researchers are at universities. Within the PROs, 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 research group has 18 members (including PhD, Masters, graduates, technicians and students of different levels, few groups include postdoctoral fellows).

The sampling frame for the firms was constructed from lists of firms that had 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 were integrated into the database of firms; 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 comprised of 325 innovative firms from all manufacturing sectors, non-innovative firms were excluded. 67% carry out R&D, 42% have fiscal incentives for R&D, and 75% have links with PROs (67% interact with universities and 47% with public research centres). The proportion between linked and non-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 PROs as an 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 PROs. Firms with foreign investment represent 33% of the total sample; they have about the same tendency to interact as nationally owned firms (70%). In terms of their size, most firms are medium-sized (42%) and large (42%), only 16% are micro-sized and small. Micro/small and large firms tend to interact more (80%) than medium-sized 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, the survey of firms includes a large proportion of firms that have access to public funds to foster R&D, thus they may perform R&D activities.

Construction of variables

The key variables are channels of interaction and benefits from interaction. We follow a categorisation based on the theoretical framework, summarised in the introduction to this paper, to allow comparison between countries (see also Arza, pp 473–484, this issue). To build the variables of the channels we relied on a question which asked the researchers and firms to evaluate the importance of each form of interaction. Thus, forms of interaction were classified into four 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 (see Table 1).

We built different types of benefits for researchers and firms; we followed the same *ad hoc* characterisation as was used for other countries studied in this special issue. Benefits to firms are defined as those related to long-term innovation strategies (*In*) and those related to short-term production activities (*P*) (see Table 2). To build this variable we relied on a question which asked firms to evaluate the importance of achieving specific objectives from their interaction with PROs, but we only considered the cases where firms evaluated the results from interaction as positive. We calculated the simple average from the responses that integrated each benefit.

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 benefits (*EB*) and intellectual benefits (*IB*) (see Table 3), we used the factor loadings from the factor analysis (Table A.1 in the Appendix shows the rotated matrix for benefits). This classification is similar to that proposed by Arza (pp 473–484) in this special issue.

Even though other methodological approaches could have been used for building the variables of benefits and channels, these constructs prioritise comparability between the 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 analysed knowledge skills, academic collaboration, networking with firms and institutional affiliation (see Table 4).

Table 1. Channels of PRO-I 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*)
Conferences and expos Publications Graduates recently employed in industry	Traditional (*TCh*)

Notes: We used a 1–4 Likert scale which was standardised to 0.25–1
Industrial parks and internships were not included in this analysis as they show a high number of missing values

Table 2. Type of benefits for firms

Benefits related to long-term innovation strategies	Technology transfer from university Augment firm's ability to find and absorb technological information Obtain information about trends in R&D in field Contract research to contribute to firms' innovative activities Contract research that 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 recruitment Use resources available at PRO Perform test for products/processes Help in quality control

Note: We used a 1–4 Likert scale which was standardised to 0.25–1

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

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

Characteristic	Variable	Type of variable
Knowledge skills	Degree Type of research Research field	Dummy: PhD = 1; Master's = 1; graduate = 0 Dummy: basic science = 1; technology development = 1; applied science = 0 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 team Team age	Numerical: $RH = \Sigma x_{ij} P_i / N$ Postdoctoral = 0.4, PhD = 0.4; PhD students = 0.3; Master students and researchers = 0.2; undergraduate students, college researchers and technicians = 0.1 Numerical
Networking with firms	Importance of linking with firms Initiative of collaboration	Dummy: yes = 1 (highly important); no = 0 (without importance) Dummy: firms' initiative = 1; both = 1; researchers' initiative = 0
Institutional affiliation	Type of organisation	Dummy: 1 = university, 0 = public research centres
Channels of interaction	Bi-directional Traditional Services Commercial	Index 0.25–1 to measure importance of each form of interaction
Benefits	Intellectual Economic	Factor loads from factor analysis

For firms we analysed variables related to innovative capabilities, firms' characteristics, strategy, and the role they perceive for PROs (see Table 5). Regarding strategy, one of the variables we analysed was their openness. We drew on Laursen and Salter (2004)[5] to build four factors by principal components that express the firm's openness to obtaining information from external sources.[6]

Model and estimation procedures

This paper built a Heckman 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

Table 5. Variables for analysing PRO-I linkages from firms' perspective

Characteristic	Variable	Type of variable
Innovative capabilities	Human resources in R&D Formalisation of R&D and innovation activities	Numerical: human resources in R&D as % of total employment Dummy: formal and continuous innovative activities = 1; otherwise = 0
Firms' characteristics	Firm size Technology sector Ownership	Numerical: *ln* of firms' employees Categorical: 0.25: low; 0.5: medium-low; 0.75: medium-high; 1: high Dummy: foreign investment = 1; otherwise = 0
Strategy	Openness strategy F1–F4 Fiscal incentives for R&D	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. 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 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 importance of each individual benefit

correct the selection bias (see Equations (1a), (1c), (2a) and (2c) below).

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 conceptualised one equation for each type of benefit for researchers and firms. The vectors of the independent variables are those features of researchers and firms that determine the benefits from interaction. The critical independent variables are the channels of interaction (Ch_i). From the design of the questionnaire, we can assume causality between the 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 the introduction to this paper 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 features of the researchers and firms (R_i and F_i, respectively) that may determine the benefits from interaction (see Equations (1b), (1d), (2b) and (2d) below).

We use the following two sets of equations, one for researchers and another for firms:

Researchers' perspective:

$$d\_V = RV_i\beta + \mu_i \quad (1a)$$

$$IB_i = Ch_i\alpha + R_i\delta + \varepsilon_i \quad (1b)$$

$$d\_V = RV_i\beta + \mu_i \quad (1c)$$

$$EB_i = Ch_i\alpha + R_i\delta + \varepsilon_i \quad (1d)$$

where RV_i is the degree, type of research, research field, member of a research team, importance of linking with firms, and type of organization; R_i is the degree, research field, human resources in the team, team age, initiative of collaboration, type of organisation; IB denotes the intellectual benefits; and EB denotes the economic benefits.

Firms' perspective:

$$d\_V = FV_i\beta + \mu_i \quad (2a)$$

$$PB_i = Ch_i\alpha + F_i\delta + \varepsilon_i \quad (2b)$$

$$d\_V = FV_i\beta + \mu_i \quad (2c)$$

$$InB_i = Ch_i\alpha + F_i\delta + \varepsilon_i \quad (2d)$$

Where FV_i is the formalisation 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 is the human resources in R&D, formalisation of R&D and innovation activities, firm size, technology sector, ownership, openness strategy, and fiscal incentives for R&D; PB denotes the benefits related to short-term production activities; and InB are the benefits related to long-term innovation strategies.

We first chose the variables of the selection model that may affect the probability of linking. We then 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.

Descriptive statistics: channels and benefits

Table 6 shows the average of the 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 the bi-directional channel more (60%), particularly knowledge transfer through joint research. Firms value more the traditional channel (58%). This suggests that from the viewpoint of the firms, above all the PROs contribute with human resources creation and knowledge diffusion, while from the perspective of the researchers, the generation of knowledge has a crucial role. The commercial channel is the least important for both agents.

Regarding benefits, researchers rank intellectual benefits higher (69%) than economic benefits (56%). This suggests that researchers are knowledge driven rather than economically driven. The most important individual benefits are related to new collaborative 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 recruitment, which is related to short-term production activities. The most important benefit related to long-term innovation strategies is associated with absorbing technological information, which does not imply an active participation by the firm in the process of knowledge generation.

Main findings

Estimation of Heckman models I: researchers' data

Table 7 presents the results of the Heckman model for Equations (1a) and (1b) for intellectual benefits and Equations (1c) and (1d) for economic benefits.

Equations (1b) and (1d) show the results of the specific channels and other factors that determine

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 exhibitions	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

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 PROs (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 of the benefits from the bi-directional channel, whether or not researchers can capitalise on the benefits from this interaction depends on their having a strong focus on research (see Perkmann and Walsh, 2009).

In contrast, we found a significant, negative and high coefficient for the commercial channel. If we look at the cases of patents and technology licenses included here, they have a double aspect: on the one hand they protect the knowledge generated through interaction and, on the other hand 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 interactions (Cohen *et al*., 2002; D'Este and Patel, 2007), however, it was quite important for Korea (Eon and Lee, 2009). In any case, this negative impact on benefits does not seem to be a common feature in developed countries.

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 for PhDs. Even though having a Master's or a PhD negatively relates to the likelihood of connecting, once researchers are linked, they can obtain more intellectual benefits if they have a postgraduate degree. Referring to academic collaboration, we found different impacts on benefits. On the one hand, 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 generation of ideas. In contrast, researchers obtain less economic benefits, as resources have to be distributed across a larger number of researchers. On the other hand, 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 obtain more economic benefits. In contrast, the experience of the team does not contribute to obtaining more intellectual benefits, which suggests that routinisation does not contribute to the flourishing of ideas. Whoever takes the initiative to collaborate also has important impacts on benefits. As the university takes the initiative, it is more likely that researchers will obtain

Table 7. Heckman estimates of economic and intellectual benefits for researchers

	Selection (1a)	Intellectual benefits (1b)	Selection (1c)	Economic benefits (1d)
Master	−0.6401**	0.5444*	−0.7716**	−0.2689
	(0.3162)	(0.3192)	(0.3109)	(0.3592)
PhD	−1.2633***	0.6630***	−0.9215***	0.0571
	(0.2603)	(0.2310)	(0.2360)	(0.2706)
Chemistry & biology	0.1999	−0.1885	0.2099	0.0776
	(0.1812)	(0.2664)	(0.1919)	(0.2294)
Medicine & health sciences	−0.6124**	−0.1942	−0.3529	0.1564
	(0.2921)	(0.4322)	(0.2612)	(0.3800)
Biotechnology & agronomy	1.1861***	−0.2436	1.0305***	−0.1869
	(0.1800)	(0.2244)	(0.2014)	(0.2246)
Engineering	0.4770***	−0.3317	0.5216***	−0.2156
	(0.1653)	(0.2260)	(0.1629)	(0.2079)
Basic science	0.5543***		0.4924**	
	(0.1379)		(0.2108)	
Technology development	0.8822***		0.6772**	
	(0.1682)		(0.3355)	
Member of a research team	0.4668***		−0.0539	
	(0.1376)		(0.2041)	
Team age		−0.0087*		0.0116**
		(0.0053)		(0.0058)
Human resources in team		0.0062*		−0.0081**
		(0.0029)		(0.0030)
Type of organisation	−0.5716***	0.1366	−0.4057***	0.0838
	(0.1240)	(0.1181)	(0.1166)	(0.1345)
Importance of linking with firms	1.6300***		1.5660***	
	(0.1131)		(0.0981)	
Firms initiate collaboration		−0.2751*		0.1713
		(0.1593)		(0.1967)
Both initiate collaboration		−0.2182		0.0623
		(0.1175)		(0.1273)
Traditional channel		0.8433*		0.1534
		(0.4501)		(0.3618)
Bi-directional channel		0.7082**		0.1725
		(0.3578)		(0.3501)
Services channel		0.4699		0.1718
		(0.3798)		(0.4211)
Commercial channel		−1.0629***		0.0039
		(0.3180)		(0.3274)
_cons	−0.0382	−0.6854*	0.0152	0.0173
	(0.3067)	(0.3547)	(0.4724)	(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

Notes: *p ‹ 0.1; **p ‹ 0.05; ***p ‹ 0.005
Results from selection Equations (1a) and (1c) are fairly similar, which increases robustness of our model

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 (1a) and (1c), we can learn that according to the researchers' perspective the main drivers for interaction are associated with three types of factor:

- knowledge skills: researchers' degree, research field and type of research;
- academic collaboration: member of a research team; and
- institutional affiliation: type of organisation: public research centre or university.

Researchers without a 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 in terms of 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. With regard to the type of research, researchers who 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.

Estimation of Heckman models II: firms' data

Table 8 presents the results of the Heckman model for Equations (2a) and (2b) for benefits related to short-term production activities and Equations (2c) and (2d) for benefits related to long-term innovation strategies.

Equations (2b) and (2d) show the channels and other factors that contribute to firms obtaining benefits from interacting. 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 PROs through formal interactions, such as joint and contract R&D projects, obtain more significant benefits. Along the same lines, Arvanitis *et al*. (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 training employees has a positive impact on innovation and productivity. The traditional channel

Table 8. Heckman estimates of production and innovation benefits for firms

	Selection (2a)	Production-related benefits (2b)	Selection (2c)	Innovation-related benefits (2d)
Human resources in R&D		0.0022** (0.0009)		0.0025** (0.0010)
Formalisation of R&D and innovation activities	−0.02810 (0.3025)	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

Notes: *p ‹ 0.1; **p ‹ 0.05; ***p ‹ 0.005
Results from selection Equations (2a) and (2c) are fairly similar, which increases robustness of our model

only has a positive impact on production-related benefits, which suggests that the 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 formalisation 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 *et al*. (2009), which argued that benefits in terms of exploration or exploitation activities depend on a firm's ability to innovate. In contrast, the latter suggests that formalisation of R&D and innovation activities by Mexican firms is more related to solving production problems than to innovating.

We found that a firm's openness strategy, based on consultancy and research projects with other firms, allows them to obtain more long-term innovation benefits from interactions with PROs. 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 may be that as firms increasingly gain access to publications, technical reports and other open sources, they gradually develop the capabilities to solve short-term production problems, previously solved with the help of PROs, or they find other external sources of knowledge to solve their production problems.

Although fiscal incentives for R&D drive linkages with PROs, they are negatively related to both types of benefits. These apparently contradictory results focus attention on discussing the role of this policy instrument in fostering linkages. Originally designed to boost R&D activities amongst firms, engagement with knowledge producers (such as PROs) was not a direct aim of this instrument, but a tangential effect. Having connections with PROs increased the firms' chances of being selected as tax credit beneficiaries, thus it may 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 may explain these results.

Equations (2a) and (2c) suggest that the main drivers for interaction according to the firms' perspective are associated with two factors:

- firms' strategy: openness strategy and fiscal incentives for R&D; and
- 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 PROs than those that do not follow such a strategy toward openness. 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 PROs for the creation and transfer of knowledge tend to connect more with PROs than otherwise. These results bring some specificities of the Mexican case and deserve more analysis, however, the drivers of PRO-I are not the main focus of this paper.[7]

Conclusion

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 *et al*., 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 of the importance of the channels. Based on the assumption that there is causality between channels and benefits,[8] we argue that benefits associated with PRO-I linkages for both agents are not the same across different forms/channels of interaction. 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 PROs 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 economically driven, as they value the impacts of interaction on intellectual rather than on economic benefits. Firms tend to connect to domestic PROs to obtain both short-term problem-solving and insights for long-term innovative strategies. The importance of the bi-directional channel supports the emphasis placed 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 forms of interaction other than joint or contract research to induce knowledge transfer and foster innovation.

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 in Mexico, and the effort required to link through these forms of interaction is much higher that the benefits obtained from them. This suggests that recent innovation policy efforts to foster the commercialisation of research neglect the perceptions 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 PROs through the mobility of the graduates, as argued by Wright *et al*. (2008). As the traditional and the services channels imply unilateral provision of intellectual resources and outputs from PROs, 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 that researchers can be more motivated, or change the incentives and forms of evaluation of researchers so that these interactions can generate some benefits.

The significance of the drivers related to perceptions about the partner, from both 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. Additionally, obstacles for PRO-I interactions include 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 policy-makers should give serious consideration to the weaknesses of PRO-I links derived from the lack of competition in different sectors and markets. Policy-makers should also be attentive 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 helped to foster PRO-I interactions, but benefits have not yet been obtained from these interactions. Learning through interaction may have been a by-product of this program, showing the potential benefits that could be obtained from that relationship. Policy instruments like this may help to overcome barriers to interaction, but the analysis of those impacts requires further investigation.

Finally, policy-makers concerned with fostering PRO-I linkages should also promote activities related to forms of interaction looking for the best articulation of the 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.

Appendix

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

Notes: Extraction method: principal component analysis rotation method: Varimax with Kaiser normalisation
Rotation converged in three 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	0.183	0.142	0.076	0.911
Customers	0.061	0.024	0.876	0.137
Competitors	0.433	0.182	0.509	−0.226
Joint or cooperative projects with other firms	0.114	0.626	0.365	0.165
Consultancy with R&D firms	0.016	0.849	−0.076	0.059
Publications and technical reports	0.603	0.449	0.090	−0.095
Exhibitions	0.693	−0.088	0.204	0.119
Internet	0.773	0.090	−0.011	0.222

Notes: Extraction method: principal component analysis. rotation method: Varimax with Kaiser normalisation

Notes

1. In this paper we use the term PROs to refer to universities and public research centres. 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.
2. The international research project is titled 'Interactions between universities and firms: searching for paths to support the changing role of universities in the South'. It was developed under the umbrella of the 'Catching up' project. It was sponsored by the IDRC (Canada). It compares the PRO-I interactions of 12 countries from Latin America, Asia and Africa.
3. Adeoti *et al*. (2010), Eom and Lee (2009), Eun (2009), Intarakumnerd and Schiller (2009), Joseph and Abraham (2009), Kruss (2009), Rasiah and Govindaraju (2009) have discussed other results of this project.
4. 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 journals cited by ISI (Thomson Scientific).
5. Laursen and Salter (2004) argue that management factors, such as firms' strategy of relying on different types of information sources, among others, are important drivers to collaborate and obtain the benefits from the 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.
6. The common explained variance by these factors is 66.1%. See Table A.2 in the Appendix for a better description of the factor analysis.
7. See Torres *et al.* (2009) for the analyses of the drivers in the Mexican case.
8. As discussed in the section on 'Model and estimation procedures', we can affirm that this causality actually exists for researchers. We rely on the theory to support this argument for firms.

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