Interactions between public research organisations and industry in Argentina: analysis of channels and benefits for researchers and firms[*]

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Abstract

There are various channels for the exchange of knowledge between public research organisations (PRO) and industry (I). This paper discusses the relative effectiveness of different channels. We use micro-data from surveys on firms and researchers to confirm that specific channels of PRO-I interactions are predominantly associated with specific types of benefits. We show that firms' innovative capabilities and researchers' knowledge skills interfere in the channels-benefits relationship. Therefore, the promotion of PRO-I interactions should be designed in accordance with the types of benefits being targeted and taking account of the knowledge characteristics of the actors involved in the interaction.

Keywords: PRO-I interactions; firms; public research institutes; universities; channels of interaction; science, technology and innovation policy; developing countries; Argentina

[*] This study is based on an international research project "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 IDRC (Canada). It compares PRO-industry interactions in 12 countries from Latin America, Asia and Africa. The questionnaires were discussed by the whole team.

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I) Introduction

Universities and public research institutes (referred to here as public research organisations, PRO) are fundamental to national socioeconomic development because they are key actors in the creation and dissemination of knowledge within the National System of Innovation (NSI).

Until the 1980s, this role was strongly associated with PRO functions based on the linear model of innovation. In addition to training graduates, universities were responsible for producing *basic* scientific knowledge. Firms and other institutions better connected to the market, in their turn, were responsible for converting this knowledge into technological solutions through performance of *applied* research. In other words, the technological effects of PRO outputs for society were achievable only through the subsequent efforts of other mediating institutions.

Since the mid 1980s, most PRO worldwide have been encouraged to make a more direct contribution to industrial innovation. Science and technology (S&T) policies targeting PRO have shifted from the promotion primarily of scientific developments, to strengthening the linkages to other key actors in the NSI. This change emerged from critical reflection on the adequacy of the linear model of innovation (Dasgupta and David, 1994, Nelson, 2004, Pavitt, 2001, Slaughter and Leslie, 1997) and PRO needs for increased funding.

The rapid increase in PRO-I interactions produced a large body of literature analysing these interactions and their effects on the whole NSI. Most studies highlight the potential of PRO-I interactions for creating benefits for both PRO and industry. Firstly, PRO broaden industry capacity to solve concrete problems, which promotes incremental innovation. Some problems demand combinations of technology that no single firm could develop independently, but which is available from the knowledge stock in PRO (Patel and Pavitt, 1995). Secondly, PRO develop new laboratory instruments and analytic methodologies that constitute fundamental inputs for industry (Rosenberg, 1992). Thirdly, from the viewpoint of scientific development, many fields of research receive their inspiration from industry (Nelson, 2004, Rosenberg, 1996, Rosenberg and Nelson, 1994); therefore, PRO-I interactions make the former's production more dynamic. Finally, PRO-I interactions allow PRO access to new sources of funding for their research (Geuna, 2001).

However, the relation between PRO and the private sector engenders some controversies, the main ones being related to: i) the goals of public research;[1] ii) the opportunity costs of linking;[2] and iii) the risk of privatisation of public research

[1] Firstly, there may be conflicts of interest between ideal behaviour to improve teaching and research activities and behaviour necessary to support and sustain interactions with private actors. This has been studied in the area of clinical research; see Blumenthal *et al.* (1997), Blumenthal *et al.* (1996), Blumenthal *et al.* (2006), Campbell and Blumenthal (1999), Gelijns and Thier (2002). Secondly, interaction with the private sector may divert researchers from socially more useful work; see Parkinson and Langley (2009).

[2] Time spent on interactions means less time for teaching and research; see e.g. Blumenthal (1996), Campbell and Slaughter (1999), Florida (1999), Godfrey (2005), Lee (1996), Mollis and Marginson (2002), Slaughter *et al.* (2002).

outputs.[3] So, taking account of the fact that PRO-I interactions may not be *cost-free*, more careful and selective promotion of interactions is required to optimize the overall effects on the NSI.

Argentinian S&T policies follow international trends. During the years after WWII S&T policy primarily supported research done in PRO. In fact, most existing public technology institutes were created in that period. However, since the 1990s, S&T policy has shifted towards promotion of firm technological activities and much wider support for PRO-I interactions which were virtually non-existent in earlier years. The establishment in 1996 of the National Agency for the Promotion of S&T represents a major institutional reform. Although PRO-I interaction has increased since then,[4] other S&T indicators suggest that NSI's performance is still poor compared to other countries in the region.[5] Although other factors may have contributed to the weak performance of Argentinean NSI, in our view fine tuning of S&T policies could have a positive effect on the current situation.

This paper contributes to better design of these policies based on an analysis of the drivers of the different types of benefits obtained by *both* actors in the interaction. We identify four channels of interaction and assess the effectiveness of each for creating benefits for firms *and* researchers. We assess also which types of benefits are driven predominantly by each channel. This should help policy makers' decisions about which channels of PRO-I interaction should be prioritised for the achievement of specific benefits.

There are few academic studies on Argentina on the process of knowledge creation and diffusion in PRO, and even fewer that focus explicitly on PRO-I interactions. Among the small number of these latter, most are based on case-studies, either focusing on firms' innovation capabilities[6] or on the dynamics of the interactions within PRO.[7] Analysis of survey data was carried out by one of the authors, using firm data (Arza and López, 2009). To our knowledge, there is no study that compares the relative effectiveness of channels of interactions for producing different types of benefits for firms and for researchers.

The paper is organised as follows: Section II presents the conceptual framework and research questions. Section III presents the data and the main descriptive findings. Section IV estimates the econometric models for the relation between channels of interactions and types of benefits. Section V concludes with some suggestions for policy.

[3] Nelson (2004) argues that fundamental knowledge from science must remain open to public use to ensure the performance of downstream research. There is evidence that firms that interact with PRO demand exclusive patent rights or secrecy; see, e.g., Blumenthal *et al.* (1996), Godfrey (2005).

[4] E.g., formal agreements between the private sector and the biggest university in the country (UBA) increased from 5 in 1990 to 455 in 1999.

[5] Notably, private sector investments in R&D are low; see Thorn (2005). E.g., in 2007, firms contributed to less than 30% of total expenditure on innovation, a much lower share than Brazil (45.5%), Chile (45.8%) and México (41.5%). Source: RICyT (http://www.ricyt.org/).

[6] E.g., Moori-Koenig and Yoguel (1998), Yoguel and López (2001) and Lugones and Lugones (2004).

[7] E.g., Dávila (2006), Juarros (2006) and Riquelme (2008).

II. Research questions and hypotheses

This paper uses data on Argentinian firms and researchers to provide empirical evidence to test the hypotheses presented in the conceptual framework developed by Arza (2010) in this Special Issue. Two research questions guide the discussion: (1) *do different channels of PRO-I interaction trigger specific types of benefits for firms and researchers? (2) do firms' and researchers' skills interfere in the relation between channels of interactions and perceived benefits*?

The conceptual framework identifies different firm and researcher motivations for interacting and argues that specific channels of interactions serve different combinations of PRO and firm motivations. Four channels of interaction are identified. The *traditional* channel (TCh) includes forms of PRO-I interactions that originate in the traditional PRO functions of teaching and research, such as publications, training graduates for employment in industry, and conference participation. The *commercial* channel (CCh) involves forms of interaction aimed at commercialising already existing knowledge outputs, for example, spin-off companies, patents and incubators. The *service* channel (SCh) attempts to solve specific production problems usually through short term interactions, such as consultancy, staff training, testing and monitoring, etc. Finally, the *bi-directional* channel (BCh) normally involves long-term, personal interaction, with knowledge flowing in both directions (from firms to PRO and vice versa), such as joint R&D projects.

Since the choice of which channel to use responds to the specific motivations of firms and researchers, and given that the benefits to each actor are likely to be in line with their original motivation for interacting, we are interested in whether these four channels are associated with specific types of benefits for firms and PRO. Arza (2010) points to two main types of benefits for firms (linking may contribute primarily to *short-term production activities* or to *long-term innovation strategies*) and two main types of benefits for PRO (i.e. *economic* or *intellectual*).

The conceptual framework suggests also that the relation between the channels of interaction and benefits is mediated by researchers' knowledge skills and firms' innovative capabilities. In this paper we attempt to identify the channels that require high level skills and capabilities to obtain specific benefits.

III) Survey results for researchers and firms in Argentina

3.1. Data collection

The *firm survey* provides micro data and is based on a subsample of the National Survey of Technological Innovation (ENIT); the fieldwork was carried out in December 2007 to gather data for 2006. The survey was managed by the National Institute of Statistics and Censuses (INDEC). The ENIT sample was constructed to be representative of the Argentinean manufacturing sector: it included 2,055 firms in the original sample and achieved a response rate of 73 per cent (1,500 firms). The questionnaire included a separate section on PRO-I interactions which was sent to the 590 firms that, in the previous ENIT, had indicated involvement in interactions with PRO. The response rate for this section was 60 per cent (354 firms). Another section on PRO-I interaction was administered to a control group of 384 firms that had had no previous interactions with PRO. This group was selected to be as similar as possible to the group of linked firms in

terms of size and sector affiliation. The response rate in this case was 62 per cent (238 firms).[8] Thus, the final sample includes 354 valid responses from firms with interactions with PRO in 2005 (*linked* sample) and 238 firms with no connections to PRO (*control* sample), yielding a total final sample of 592 firms.

If we compare the *linked* sample and the *ENIT* sample, which, as indicated above, is representative of the manufacturing sector, we find that firms that interact with PRO, on average tend to be larger and more innovative. While linked firms, on average, spend 2.5 per cent of their sales on innovative activities (and 0.7% on R&D), for the ENIT sample the average figures are 1.3 per cent and 0.2% respectively. Comparison of the size distribution is presented in Table 1. It can be seen that large firms are over-represented (and small firms are under-represented) in the *linked* sample, in terms of both employees and sales.

Table 1: Size Distribution of Firms (by employment and sales)

	***Linked* sample**	**ENIT 2005**
Employees	%	%
Small: Less than 40	16.3	30
Medium: 40-116	27.3	30
Large: 116+	56.3	40
Annual sales (2005 pesos)	%	%
Small: Less than 5,898,075	13.2	30
Medium: 5,898,075-27,956,21	27.9	30
Large: 27,956,221+	58.9	40

The *researcher survey* was designed and implemented by the authors using the Argentinean Science and Technology Information System (SICyTAR) database as the sample frame. We stratified the sample across the research fields that were indicated as important in the firm survey.[9] An on-line questionnaire was sent to 2,221 researchers in late August and early September 2009. The response rate was 6.1 per cent (136 researchers) after three e-mails. Both linked and unlinked researchers were included in the survey, representing 68 per cent and 32 per cent of the sample, respectively.

Our sample of researchers comprises 30 per cent engineers from various disciplines, 25 per cent biologists and chemists, 21 per cent agronomists and veterinarians, 14 per cent physicists and mathematicians and 9 per cent surgeons and pharmacists.

The average age of the sample is 48 years and 45 per cent of researchers are women. Although the sample unit is individual researchers, some questions in the survey refer to the research group to which the respondent researcher belongs. The average size of research groups is around 12 researchers.

The survey also asked about the number of publications indexed in the ISI (Institute for Science Information) Web of Knowledge. However, this variable was judged to be

[8] Due to the fact that the response rate was not 100% in either case, linked and control firms do not show exactly similar sizes and sector distributions.

[9] These are: industrial design, chemical engineering, materials engineering and metallurgy, mechanical engineering, electronic engineering, chemistry, food science and technology, computer science and agronomy.

inaccurate: some answers were suspiciously high, which made us believe that the quality criterion (i.e. indexed in ISI) was being ignored.

3.2. Descriptive findings for PRO-industry interaction: channels and benefits

In this section we present the descriptive results for the main variables in this investigation: channels and benefits of PRO-industry interaction. We begin by examining the importance of different forms of interaction, from both the researchers' and firms' viewpoints. The survey asked all respondents to rank different forms of interactions according to their importance, on a four-point Likert scale.[10]

Evidence from Argentinian researchers (last column in Table 2) suggests that consultancy, informal information exchange and conferences are the most valued forms of interaction, with respectively 79 per cent 45 per cent and 44 per cent of respondents considering those forms as, at least, "moderately important". Co-operative R&D, research contracts, training staff, recently hired graduates and publications follow in importance, with similarly-defined scores in the range of 25 to 38 per cent. Networking (18%), licensing (13%) and personnel exchange (12%) are less important. Finally, the least important options with fewer than 10% of researchers considering them as at least "moderately important" are patents, science parks, incubators and spin-offs.

In the case of firms (last column in Table 3), informal information exchange, publications and conferences are clearly the most important forms of interaction with 51 per cent, 47 per cent and 46 per cent of firms assessing them respectively as, at least, "moderately important". Recently hired graduates, consultancy, co-operative R&D and research contract follow, with similarly-defined proportions in the range of 27 to 24 per cent. A third set of forms includes licensing (16%), networking (15%), patents (15%) and science parks (12%). Finally, personnel exchange, incubators, firms owned by PRO and spin-offs are the least important according to firms, with similarly-defined scores under 10%.

These results are consistent with the results of other survey-based studies. Although a large part of the growing literature on channels of knowledge transfer focuses on formal mechanisms and intellectual property rights (IPRs), there is evidence suggesting that others channels prevail in PRO-industry interactions (Agrawal and Henderson, 2002, Cohen *et al.*, 1998, Cohen *et al.*, 2002, D'Este and Patel, 2007, Meyer-Krahmer and Schmoch, 1998).

Forms of interactions are grouped to proxy the four channels proposed by Arza (2010): *Traditional*, *Services*, *Bi-directional* and *Commercial*. This aggregation is done in a similar way for researchers' and firms' data (see Tables 2 and 3).[11] These channels are the main explanatory variables in the estimations of the econometric models in Section IV. The evidence presented so far suggests that *Traditional* and *Services* channels are

[10] The question to researchers was formulated: "Select the main channels of interaction with firms and state their degree of importance for transferring knowledge? (1 Not important, 2 Of little importance, 3 Moderately important, 4 Very important)" The question in the firm questionnaire was worded: "Please, qualify the following channels according to their importance for innovative activities in the firm (1 Not important, 2 Of little importance, 3 Moderately important, 4 Very important)". Researchers and firms could indicate as many options as they wanted to.

[11] Exceptions are "training staff", which was an option included only in the researcher survey and "firm is owned by a PRO", which was an option only in the firm survey.

considered by firms and researchers as the most important channels of PRO-industry interactions in Argentina. The former is relatively more important for firms and the latter relatively more important for researchers. All forms included in the *Commercial* channel are considered important less frequently, presumably because they are less frequently exploited by firms and researchers.

Our research question involves enquiring about the benefits of PRO-industry interaction for both sets of actors.

The researcher survey included a question that directly asked about the benefits associated to interaction with industry.[12] Table 2 presents the importance of each kind of benefit and the grouping, to proxy *Intellectual* and *Economic* benefits proposed by Arza (2010).[13]

Researchers in our sample allocate significantly higher importance to intellectual than to economic benefits.[14] Reading across the last row in Table 2, the most important in relation to the former are sharing knowledge and information (75% of researchers consider this as at least "moderately important"), inspiration for further scientific research (70%) and ideas for further collaboration projects (66%). Among the economic benefits, access to financial resources was seen as an important benefit (64%), followed by provision of research inputs (45%) and sharing equipment (35%).

Researchers working in fields closer to what Stokes (1997) refers to as *Pasteur's quadrant*, which involves simultaneous performance of basic and applied research (e.g. all types of engineering, biotechnology, metallurgy, computer science, etc), usually achieve greater intellectual benefits than researchers working in fields where the knowledge is less applied and the potential for learning from interaction, therefore, is smaller (p-value 0.07). In terms of economic benefits, research field does not seem to have an influence.

Unfortunately, our firm survey does not provide information about the benefits of interactions. Thus, we need to proxy for benefits using a question about the objectives of interaction[15] combined with another question about the extent to which the objectives were achieved. In other words, we regard *benefits* as *goals* achieved or expected to be achieved.[16] Table 3 presents the different types of benefits built using the available data.

The last row in Table 3 shows that testing and help in quality control are the main benefits for firms with 43 per cent of respondents indicating the former as, at least "moderately important" and 38 per cent indicating similar value for the latter. Obtaining technological advice (30%), early contact with students (25%) and technology transfer

[12] The question was worded as follows: "What are the main benefits to the research group and to the institution of collaborating with the private sector?" Researchers could choose as many options as they wanted from those listed in the columns in Table 2. They were asked also indicate the "level of importance" of each on a four-point Likert scale going from "not important" to "very important".
[13] This classification was confirmed by factor analysis exercises.
[14] The fact that the survey respondents were individual researchers rather than PRO managers may have biased these results. Although the question refers to the benefits to researchers and their institutions, it may well be that the latter are under-valued in the responses of individual researchers.
[15] The firm questionnaire asked: "What are the goals of your collaboration with universities and/or public research institutes? Please, qualify the following goals according to their importance" The options were: 1 Not important, 2 Of little importance, 3 Moderately important, 4 Very important.
[16] Unachieved goals were treated as unimportant goals (i.e. no benefit).

(21%) were ranked next in importance. Finally, the benefits perceived as least valuable are: using resources allocated in PRO (20%), augmenting absorptive capacities (18%), getting information about scientific trends (17%) and contract research (13%).

The different types of benefits are grouped into two categories to proxy the classification proposed in Arza (2010): benefits related to firms' short-term *production* activities, and benefits related to firms' long-term *innovation* strategies.[17] Clearly, Argentinean firms perceive production benefits as more important than benefits associated with innovation.

Table 2: % of researchers that rank each type of benefit and each form of interaction as at least "moderately important"

		Economic (EB)			Intellectual (IB)				Total
		Share equipment / instruments	Provision of research inputs	Financial resources	Inspiration for further scientific research	Share of knowledge/information	Ideas for further collaboration projects	Reputation	
Traditional (TCh)	Publications	14%	16%	16%	20%	20%	19%	18%	**25%**
	Conferences and expos	20%	24%	30%	31%	36%	35%	30%	**44%**
	Graduates employed recently in the industry	14%	17%	18%	22%	25%	22%	18%	**29%**
Services (SCh)	Consultancy	32%	39%	52%	60%	64%	57%	48%	**79%**
	Personnel Exchange	9%	9%	9%	10%	11%	11%	9%	**12%**
	Training staff	17%	20%	22%	25%	27%	25%	22%	**29%**
	Informal information Exchange	24%	27%	32%	38%	36%	36%	32%	**45%**
Bi-directional (BCh)	Research contract	17%	19%	28%	32%	33%	31%	27%	**37%**
	Networking	9%	10%	13%	16%	16%	16%	15%	**18%**
	Scientific parks	6%	5%	7%	6%	8%	7%	5%	**9%**
	Co-operative R&D	17%	22%	30%	32%	35%	33%	30%	**38%**
Commercial (CCh)	Spin-off	5%	6%	5%	6%	7%	6%	5%	**7%**
	Incubators	5%	5%	7%	8%	8%	7%	7%	**9%**
	Licensing	8%	8%	11%	13%	11%	10%	10%	**13%**
	Patents	7%	7%	8%	10%	9%	9%	8%	**10%**
Total		**35%**	**45%**	**64%**	**70%**	**75%**	**66%**	**56%**	

Source: Researchers' Survey

[17] This classification was confirmed by factor analysis exercises.

Table 3: % of firms that rank each type of benefit and each form of interaction as at least "moderately important"

		Innovation (Long-term) InB				Production (Short-term) PB					Total
		To contract research that substitute research that the firm do not perform	Technology transfer from the university	To augment the firm's limited ability to absorb technological information	To get information about engineers or scientists or trends	To get technological advice	To make earlier contact with excellent university students	To use resources available at PRO	To perform tests necessary for products or processes	To help in quality control	
Traditional (TCh)	Publications	9%	14%	13%	12%	18%	15%	13%	22%	22%	**47%**
	Conferences and expos	9%	16%	13%	13%	18%	18%	14%	22%	21%	**46%**
	Graduates employed recently in the industry	6%	9%	8%	9%	11%	14%	8%	14%	13%	**27%**
Services (SCh)	Consultancy	8%	11%	9%	8%	12%	12%	11%	15%	13%	**27%**
	Personnel exchange	4%	4%	4%	4%	6%	6%	5%	5%	6%	**10%**
	Informal information Exchange	10%	17%	13%	14%	21%	17%	15%	24%	24%	**51%**
Bi-directional (BCh)	Research contract	8%	11%	8%	9%	11%	11%	10%	13%	12%	**24%**
	Networking	6%	8%	6%	7%	7%	7%	6%	8%	8%	**15%**
	Scientific parks	4%	7%	5%	5%	6%	7%	6%	7%	6%	**12%**
	Co-operative R&D	8%	12%	9%	9%	13%	12%	10%	14%	15%	**25%**
Commercial (CCh)	Spin-off	0%	1%	1%	1%	1%	1%	1%	1%	1%	**2%**
	Incubators	2%	3%	2%	2%	3%	3%	2%	3%	3%	**5%**
	Licensing	4%	7%	5%	4%	7%	8%	5%	8%	8%	**16%**
	Patents	3%	6%	5%	4%	7%	7%	4%	7%	7%	**15%**
	Firm owned by PRO	0%	1%	1%	1%	1%	1%	1%	1%	1%	**3%**
Total		**13%**	**21%**	**18%**	**17%**	**30%**	**25%**	**20%**	**43%**	**38%**	

Source Firms' Survey

Tables 2 and 3 also provide some interesting results in terms of the relationships between forms of interactions and types of benefits. We compare actual frequency distribution of cells with theoretical frequency if rows (i.e. forms of interactions) and columns (i.e. all types of benefits) were independent (i.e. the product of marginal probabilities). In the case of firms, conferences, informal information exchange and co-operative R&D are the forms of interaction related especially to the benefit of access to new technology from PRO. In the case of researchers, R&D collaboration with firms is a form of PRO-I interaction related to the intellectual benefits of reputation and ideas for future projects. Finally, interacting informally provides researchers with economic benefits from sharing (possibly hiring) equipment and instruments.

IV) Main econometric results

4.1. Econometric Models

In order to identify the determinants of the benefits we estimate two sets of equations, one for researchers and another one for firms, following Arza (2010).

Models

I) Researchers

$$\textbf{(1.1)}\ d\_V = RV_i\beta + \mu_i$$

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

$$\textbf{(1.3)}\ d\_V = RV_i\beta + \mu_i$$

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

II) Firms

$$\textbf{(2.1)}\ d\_V = FV_i\beta + \mu_i$$

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

$$\textbf{(2.3)}\ d\_V = FV_i\beta + \mu_i$$

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

The conceptual framework suggests that different channels of interactions (Ch_i) have the potential to trigger different kinds of benefits, for both researchers (intellectual -IB_i- and economic –EB_i-) and firms (benefit related with production activities -PB_i- and with innovative activities –InB_i-). Other researcher and firm features (R_i and F_i respectively) may affect these benefits, and, therefore, are included as control variables in the equations. These control variables are informed by the literature and include, among others, proxies for concepts such as experience and knowledge skills in the case of researchers and innovative capabilities and networking capabilities in the case of firms.

To deal with potential selection bias (i.e. special characteristics of interacting researchers and firms) we use the Heckman's two-step method with robust standard errors. For the selection part of each Heckman model (eq. 1.1, 1.3, 2.1 and 2.3), the dependent variable (d_V_i) is a dummy variable that equals 1 when the firm or researcher is linked. The vectors of independent variables in these equations are the researcher

(RV_i) and firm (FV_i) features that affect the probability of linking. We use Bayesian Information Criterion (BIC) to optimise the fit across different specifications (i.e. proxies) of independent variables.

4.2. Estimation of Heckman *models I*: researchers' data

Table 4 presents the results for the Heckman model estimated with robust standard errors for the equations on intellectual and economic benefits (see columns 1 to 4). Columns 1 and 3 are estimations for the selection equations (i.e. the probability that researchers interact with firms). These estimations are used to correct for selection bias in the estimation of benefits (columns 2 and 4).[18] All variables used in the estimations are listed and described in full in the Annex (see Table B).

The explanatory variables in the selection model are based on the literature. In the case of researchers, the literature studied both individual and institutional characteristics (e.g. university policies) to explain the probability of engagement in interaction with the private sector. Here, we focus on researchers and their research groups. According to the literature, the main drivers of linking for individual researchers are research field, career experience, perception of PRO-I (i.e. positive attitude towards interaction) and research group size (Agrawal and Henderson, 2002, Bercovitz and Feldman, 2003, D'Este and Patel, 2007, Landry *et al.*, 2007).

Specification of the selection part that best fits our data includes the explanatory variables researcher's gender, size of his/her research group, and proxies for research field, knowledge skills and perception of PRO-I. In the case of research field, we use a 0-1 index that accounts for the extent to which the field belongs to *Pasteur's quadrant* (see Annex B). For research group knowledge skills, we include the proportion of students in the group.[19] Finally, to proxy for attitude to PRO-I, we use information derived from a question about the importance of the different roles of universities[20] and create a dummy that equals 1 if the researcher sees collaboration with industry is a *very important* role for the university.

In the estimation of benefits the main explanatory variables are the four channels of interaction. We control also for other characteristics of the researcher and research group, such as gender, experience, size and knowledge skills.

The results of the selection equations (column 1 and 3 in Table 4)[21] are not discussed here: we want to keep the focus on the relation between channels and benefits. The aim

[18] In the case of researcher data, there seems to be a significant correlation between residuals of the selection and outcome equations for intellectual benefits, which would have triggered bias had equation 1.2 been estimated using ordinary least squares.

[19] As in the case of other drivers, we tried different proxies and selected the one that maximised the model fit using the BIC criteria. In the case of knowledge skills we used *formal training of the researcher, formal training of the research group, researcher's experience, research group's experience, proportion of post-graduate researchers* in the group and *proportion of students*. BIC criteria indicate the last as being most appropriate. Since we also control for group size, this indicator can be used as a proxy for the group's knowledge skills: in groups of the same size, if the proportion of students is higher we can assume that the overall knowledge skills of the group will be lower.

[20] The possible roles are teaching, research, collaborating with the community and collaborating with industry.

[21] Estimation results for the selection part in both models are fairly similar, which increases the robustness of our results.

of the selection part of the equation is purely instrumental: to control for the possibility of selection bias. However, the signs and significance of coefficients in general are as expected.

The results of the main outcome equations (estimation of benefits for researchers, columns 2 and 4 in Table 4) suggest that intellectual benefits are positively affected by gender; linked women achieve greater intellectual benefits. In terms of the main explanatory variables, it should be remembered that the four channels were built by calculating the mean of different forms of interactions, all of which were optional responses to the same question in the survey. Thus, we can expect multicollinearity among these channels. In fact, the Pearson correlation coefficients for these channels are usually above 0.40 when calculated using researcher data (see Table A in the Annex). Multicollinearity does not bias the coefficient, but it inflates the standard errors, which affects significance levels. This explains why when channels are included separately in the estimations, almost all appear to be significant –although the size of the coefficients does not change much compared to the coefficients when all channels are included together. By including all channels together in the regression, we neglect those with relatively weaker explanatory power and allow the explanatory power of most important ones to take over.

The *bi-directional* channel of interaction is a key driver of intellectual benefits. On average an approximately 1% increase in the importance of the bi-directional channel, increases intellectual benefits by 0.3%.[22] However, it does not seem to affect economic benefits. On the other hand, the *service* channel is important for both types of benefits and especially economic where elasticity is around 0.5.

The *commercial* channel has a negative impact on intellectual benefits. This is not surprising since this channel implies the economic exploitation of PRO's past intellectual achievements and, intellectual benefits, as measured here, relate most to the possibility of future research by the research group. The commercial channel includes forms of interaction, such as *incubators* and *spin offs*, which, by definition, privatise any further output that PRO could have produced. Similarly, if licences involve exclusive rights, this may affect the PRO downstream research. This negative impact suggests that somehow this channel results in lack of opportunity in terms of further research within PRO.

Since researchers' knowledge skills may interfere with the relative effectiveness (in driving benefits) of these channels of interaction, as suggested by Arza (2010), columns 5 to 8 in Table 4 include interaction effects between channels and knowledge skills (proxied by a dummy measuring the relative intensity of group members' formal training above or below the sample median, see Annex Table B). This produces some interesting results. For the *bi-directional* channel, research groups with knowledge skills above the median, as expected, receive significantly higher *intellectual benefits* than research groups with knowledge skills below the median. However, only the latter group receives intellectual benefits when interaction with firms is via the *service* channel. This implies perhaps that this channel transmits more straightforward/mature knowledge that does not advance the knowledge for more skilled researchers, but helps the least skilled ones. Similarly, the *commercial* channel has a negative effect on

[22] From this point on, interpretation of any effect of the independent variables on the dependent variables is based on the calculation of elasticity at the mean.

intellectual benefits for the higher skilled group, but not the less skilled. Finally, there are no significant differences in the *economic benefits* between groups of different skills for any of the channels.

Table 4: Heckman estimates of economic and intellectual benefits for researchers

	Selection **(1)**	Intellectual Benefits (IB) **(2)**	Selection **(3)**	Economic benefits (EB) **(4)**	Selection **(5)**	Intellectual Benefits (IB) **(6)**	Selection **(7)**	Economic benefits (EB) **(8)**
TCh		-0.0231		0.0701				
SCh		0.376***		0.599***				
CCh		-0.234**		-0.0762				
BCh		0.407***		0.0820				
Gender	-0.583**	0.122***	-0.570**	0.0147	-0.587**	0.128***	-0.567**	0.0148
group_form		0.289		0.108				
size_rg	0.0455**	-0.00163	0.0524**	-0.00155	0.0446*	-0.00187	0.0531**	-0.00188
std2_age		0.0205		0.0244		0.0186		0.0203
Pasteur	1.296***		1.362***		1.285***		1.366***	
prop_stud	1.217		1.111		1.100		1.139	
perc_PRO-I	1.465***		1.273***		1.476***		1.250**	
TCh_form						-0.0355		0.0247
TCh_noform						-0.0358		0.112
SCh_form						0.285		0.540***
SCh_noform						0.396***		0.608***
CCh_form						-0.265**		-0.218
CCh_noform						-0.156		-0.0106
BCh_form						0.636***		0.268
BCh_noform						0.278**		-0.0236
Constant	-1.778***	0.158	-1.736***	0.107	-1.749***	0.411***	-1.735***	0.214**
Observations	128	128	128	128	128	128	128	128
N_cens	42	42	42	42	42	42	42	42
Wald test of indep. eqns. (rho = 0): chi2(1)	6.342	6.342	0.0488	0.0488	4.285	4.285	0.134	0.134
Prob > chi2	0.0118	0.0118	0.825	0.825	0.0385	0.0385	0.714	0.714
Sigma	0.192	0.192	0.190	0.190	0.188	0.188	0.189	0.189
Rho	-0.661	-0.661	0.0854	0.0854	-0.647	-0.647	0.148	0.148
Wald chi2(8)	67.75	67.75	52.63	52.63	73.84	73.84	61.39	61.39
Prob > chi2	0	0	1.27e-08	1.27e-08	0	0	5.11e-09	5.11e-09
Log pseudolikelihood	-33.83	-33.83	-42.01	-42.01	-33.05	-33.05	-41.47	-41.47

*** p<0.01, ** p<0.05, * p<0.1

4.3. Estimation of Heckman *models II*: firm data

Table 5 presents the estimation of the Heckman models with firms' data. The variables included in the selection equations (columns 1 and 3) are identified in the literature as the main drivers of collaboration: size, sectoral affiliation, firm's networking capabilities, firm's innovative capabilities and public support (Cohen *et al.*, 2002, Fontana *et al.*, 2006, Laursen and Salter, 2004, Link and Rees, 1990). The signs and significance of the coefficients are as expected.

In the estimation of benefits, the main explanatory variables are the four channels of interaction. We control also for size, sector and other firm features such as innovative performance and use of public support programmes. We also include a variable to account for short-term interactions (less than 1 year) to see whether it has an effect on benefits. The variables used are listed and defined in Annex Table B.

The results are presented in Table 5. Columns 2 and 4 show the results for firm benefits. We find that small firms obtain more benefits associated with production activities, but firm size does not affect the benefits related to innovation activities. Innovative firms (those that produce successful product and process innovations) receive more benefits for innovation from interacting with PRO; however, innovativeness does not affect the benefits related to production activities. Finally, if collaboration lasts for less than a year, this reduces the intensity of the benefits.

Regarding the main explanatory variables, as was the case for researchers, the four channels are correlated (correlation coefficients all above 0.55, see Annex Table A). We find that the *traditional* channel is an important driver of firm benefits related to production and innovation activities: a 1 per cent increase in the importance of the primary functions of the PRO (teaching and research) increases either production or innovation benefits by 0.2 per cent. This is consistent with the literature that claims that PRO activities create outcomes from which the private sector benefits (Mansfield, 1991, 1998, Salter and Martin, 2001). The *bi-directional* channel drives both types of benefits but the intensity for innovation benefits doubles the intensity for production benefits (elasticity 0.4 and 0.2, respectively).

Table 5: Heckman estimates of production and innovative benefits for firms

	Selection **(1)**	Production Benefits (PB) **(2)**	Selection **(3)**	Innovation Benefits (InB) **(4)**	Selection **(5)**	Production Benefits (PB) **(6)**	Selection **(7)**	Innovation Benefits (InB) **(8)**
TCh		0.174**		0.158**				
SCh		0.180		0.0954				
CCh		-0.0193		0.0503				
BCh		0.229**		0.353***				
innov_prodproc		0.0149		0.0399**		0.0176		0.0386*
decile_workers	0.0722***	-0.00703*	0.0730***	-0.00450	0.0723***	-0.00695*	0.0732***	-0.00481
network_ac_gov		0.00675		0.0215		0.00888		0.0240
length_1		-0.0903***		-0.0656***		-0.0884***		-0.0651***
sector_ia		0.0404*		0.0435**		0.0387*		0.0459**
Network	0.809***		0.810***		0.810***		0.805***	
inhouse_sales	1.535		1.789		1.579		1.764	
fin_pub_id	1.017*		1.003		1.013*		1.014	
sector_link	0.0061***		0.0060***		0.0061***		0.00605***	
oth_link_info	-1.017***		-1.010***		-1.017***		-1.019***	
oth_link_res	0.122		0.0620		0.129		0.0618	
TCh_ih						0.180**		0.179**
TCh_noih						0.165		0.0815
SCh_ih						0.159		0.130
SCh_noih						0.263		0.0501
CCh_ih						-0.0402		-0.0189
CCh_noih						0.0708		0.241
BCh_ih						0.266**		0.351***
BCh_noih						0.0983		0.322*
Constant	-0.300	0.288***	-0.284	0.146***	-0.303	0.283***	-0.278	0.141***
Observations	590	590	590	590	590	590	590	590
N_cens	240	240	240	240	240	240	240	240
Wald test of indep. eqns. (rho = 0): chi2(1)	2.459	2.459	0.803	0.803	2.604	2.604	0.258	0.258
Prob > chi2	0.117	0.117	0.370	0.370	0.107	0.107	0.612	0.612
Sigma	0.165	0.165	0.148	0.148	0.165	0.165	0.147	0.147
Rho	-0.272	-0.272	-0.186	-0.186	-0.280	-0.280	-0.132	-0.132
Wald chi2(9)	158.1	158.1	217.3	217.3	162.3	162.3	225.6	225.6
Prob > chi2	0	0	0	0	0	0	0	0
Log pseudolikelihood	-210.3	-210.3	-177.3	-177.3	-209.8	-209.8	-176.1	-176.1
*** p<0.01, ** p<0.05, * p<0.1								

Similar to the researcher data, we include some interaction terms: in this case they are related to firms' innovative capabilities[23] and check for whether a channel's effectiveness in triggering different types of benefits changes for firms with higher or lower innovative capabilities.

We find that only firms with high innovation capabilities benefit in terms of innovation and production activities from the *traditional* channel. In other words, only firms that invest heavily in in-house activities are able to absorb this type of highly codified knowledge that does not require personal interaction.

The *bi-directional* channel produces innovation benefits for all firms, regardless of whether they are above or below the median firm in terms of investing in in-house innovative activities. This is not surprising since firms can interact with PRO through this channel to substitute or to complement in-house innovation activities. However, these capabilities are important for obtaining benefits for production, possibly because internal capabilities cannot be substituted by external sources for these activities.

V) Conclusions

The main research question guiding this paper is whether different channels of PRO-I interactions are more effective for driving particular types of benefits for firms and for researchers. We explored the secondary research question of whether this relation is affected by researchers' knowledge skills and firms' innovative capabilities. Our solutions should provide guidance for policy makers for the design of policy schemes that prioritise certain channels of interactions when particular types of benefits are being targeted.

Our descriptive results characterise current PRO-I interactions in Argentina. We find that the *Traditional* and *Services* channels are considered by most researchers and firms as the most important channels of PRO-I interactions. The former predominates for firms, and the latter, especially consultancy, received the most frequent mention from researchers. Regarding the benefits, intellectual benefits are the most important for researchers and production benefits are the most important for firms.

The econometric estimations assess the determinants of different types of benefits for firms and for researchers and especially the relative effectiveness of the channels of interactions for driving the different types of benefits for each actor.

Our results agree with the conceptual framework in Arza (2010) that the *bi-directional* channel of interaction is a key driver of intellectual and innovation benefits for firms. We confirmed the predominant importance of the *service* channel for conveying economic benefits for researchers. We found that the *commercial* channel does not produce intellectual benefits: our findings suggest that this channel even reduces intellectual benefits. Finally, as expected, the *traditional* channel creates benefits for firms' short-term production activities.

[23] This dummy takes the value 1 if the firm invests more than the median firm in in-house innovative activities.

However, in contrast to Arza (2010), our results highlight the importance of the *bi-directional* channel as a driver of short-term production benefits and the *service* channel for driving intellectual benefits for researchers. In other words, the *bi-directional* channel is important for firms seeking all types of benefits, while the *service* channel is similarly important for researchers. We also show that the *traditional* channel is a key driver of *all* types of benefits for firms with above the median innovative capabilities (i.e. firms able to absorb external knowledge).

In sum, our results highlight the relevance of the *bi-directional* and *traditional* channels for contributing to firms' benefits and the relevance of the *service* channel as a driver of researchers' benefits. However, it must be remembered that PRO in Argentina are generally underfinanced which means that interactions with the private sector probably enables researchers to obtain economic benefits and become intellectually more productive since they may be enabled to perform research that they otherwise would not be able to do. In this context, the intellectual benefits, especially those obtained through the *service* channel, should be assessed controlling for the increased budget available, as suggested by Defazio *et al.* (2009).

Finally, the results for the *commercial* channel are puzzling: increasing the importance of this channel reduces the intellectual benefits for researchers (mainly in terms of opportunities for future research). Also, our results show that this channel does not produce any positive benefits for either researchers or firms. Although the benefits derived from using this channel are relatively low worldwide, it may imply high risks (in terms of privatisation of public research outputs) for countries with low level entrepreneurial capabilities and with power asymmetries in the definition and enforcement of IPR. The effect of this channel on the strategic diffusion of publicly created knowledge should be analysed further to avoid what Nelson (2004) has called the tragedy of the scientific commons. It could have perverse socioeconomic consequences since privatisation of the knowledge created in PRO could affect downstream research and the research activities of future generations.

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Annex

Table A: Correlation matrix

Researchers' data

	TCh	SCh	BCh	CCh
TCh	1.000			
SCh	0.411	1.000		
BCh	0.449	0.457	1.000	
CCh	0.432	0.455	0.615	1.000

Firms' data

	TCh	SCh	BCh	CCh
TCh	1.000			
SCh	0.713	1.000		
BCh	0.625	0.781	1.000	
CCh	0.575	0.662	0.702	1.000

Table B: Variables' definition

Concept	Indicator / Variable name	Type of data	Definition
Traditional channel	*TCh*	Continuous	Average of all forms of interactions classified under each channel denomination (see Table 2 and 3) normalised to a 0-1 scale.
Service channel	*SCh*	Continuous	
Bi-directional channel	*BCh*	Continuous	
Commercial channel	*CCh*	Continuous	
Researchers			
Economic benefits	*EB*	Continuous	Average of all benefits classified under each type of benefit (economic and intellectual, see Table 2) normalised to a 0-1 scale
Intellectual benefits	*IB*	Continuous	
Gender of the researcher	*gender*	Dummy	1 = female 0 = male
Research field	*pasteur*	Ordinal	Depending on the research field, it takes the values: 0.2 = Physics and math 0.4 = Chemistry and biology; 0.6 = Medicine; 0.8 = Biotechnology and agronomy; 1 = Engineering and design
Size of the research group	*size_rg*	Count	Number of researchers in the research team
Knowledge skills of the research Group	*group_form*	Continuous	Weighted mean of the group member's education
	prop_stud	Continuous	Proportion of students in the research group
Experience	*std2_age*	Continuous	Squared standardization of researcher' age
Positive attitude	*perc_PRO-I*	Dummy	Researchers' perceptions about the importance of PRO-I linkages. 1 = "collaborating with the productive sector is very important"
Traditional channel – Skills interaction	*TCh_form / TCh_noform*	Continuous	All channels of interaction calculated for researchers belonging to groups above and below the median value of *group_form*
Service channel – Skills interaction	*SCh_form / SCh_noform*	Continuous	
Bi-directional channel – Skills interaction	*BCh_form / BCh_noform*	Continuous	
Commercial channel – Skills interaction	*CCh_form / CCh_noform*	Continuous	
Firms			
Short-term production benefits	*PB*	Continuous	Average of all benefits classified under each type of benefit (production and innovation, see Table 3) normalised to a 0-1 scale
Long-term innovation benefits	*InB*	Continuous	
Size	*decile_workers*	Ordinal	Deciles based on employment for the full sample
Innovative capabilities	*inhouse_sales*	Continuous	Expenditures in R&D and Design and Engineering over sales
	innov_prodproc	Dummy	1 = the firm obtained a new product and a new process
Networking capabilities	*network_act_gov*	Dummy	1 =the firm actively cooperates with ANPCYT or other S&T public program
	network	Dummy	1 = the firm links to other actors within the NSI (excluding PRO) to co-operate actively or to exchange information
	oth_link_info	1-4 scales normalized 0.25-1	Linkages with other firms: importance of forms of interaction for information exchange (i.e. publications, conferences, informal information exchange and exhibitions)
	oth_link_res	1-4 scales normalized 0.25-1	Linkages with other firms: importance of forms of interaction related to research activities (i.e. patents, licensing, co-operative R&D, research contracts, products)
Public support	*fin_pub_ia*	Dummy	1 = the firm receives public funds to finance its innovative activities
Sectoral specificities	*sector_link*	Count	Sum of firms that were connected to PRO per sector (2 digits ISIC)
	sector_ia	Continuous	Total expenditures in innovative activities over sales in each sector (2 digits ISIC) according to the full sample
Traditional channel –innovative capabilities interaction	*TChih / TChnoih*	Continuous	All channels of interaction calculated for firms that invest above and below the median value of in-house innovative activities
Service channel – innovative capabilities interaction	*SChih / SChnoih*	Continuous	
Bi-directional channel – innovative capabilities interaction	*BChih / BChnoih*	Continuous	
Commercial channel – innovative capabilities interaction	*CChih /CChnoih*	Continuous	
Length	*length_1*	Dummy	1 = the interaction lasted less than one year