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Channels and benefits of interactions between public research organisations and industry: comparing four Latin American countries

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This paper compares the results of four country studies (Argentina, Brazil, Costa Rica and Mexico) on the relative effectiveness of channels of interactions between public research organisations (PROs) and industry in driving specific types of benefits for researchers and firms. All studies used micro-datasets developed by a joint project using common questionnaires. Channels of interactions were classified into four groups (traditional, services, bi-directional and commercial) while benefits were classified into two groups for firms (short-term production and long-term innovation) and for researchers (economic and intellectual). It is found that the bi-directional (knowledge flows in both directions) and the services (knowledge flows mainly from PROs to firms) channels drive intellectual benefits for researchers. Firms tend to value the traditional channel (i.e. graduates, publications, conferences) more than any other channel. However, it is the bi-directional channel that drives the best benefits, especially those related to contributions to innovation activities.

UNIVERSITIES AND PUBLIC RESEARCH institutes, hereinafter public research organisations (PROs), have a key role in upgrading the national systems of innovation (NSI). Not only do they train graduates and contribute to the stock of knowledge from which other agents can draw, but they may also make more direct contributions to meet the demands of knowledge from the society. In this paper we concentrate on the PRO–industry (PRO-I) interactions, which may imply direct contributions by PROs to technological accumulation by firms as well as new sources of inspiration and fields of application for their research activities.

A set of factors has shaped the various national systems of interaction in Latin American countries. First, the institution-building process has been eclectic as a consequence of various swings in policy regimes. In particular, institutions that had emerged in response to import substitution policies from the 1940s to the 1960s co-existed with more modern institutions devised in agreement with the liberalisation policies of the period from the 1970s to the 1990s. This mix sometimes implies a lack of consistency in policy guidelines. Secondly, persistent macro-instability and dramatic crises (in the 1980s, 1990s and currently) have affected the long-term behaviour and performance of firms in the region. Thirdly, neither economic nor social policies have been effective in alleviating poverty or inequality. Moreover, to some extent existing uneven social structures feed back into unfair policy-making. In fact, income inequality enhances power asymmetries, thus undermining the possibility of building a durable consensus. Without consensus, public policy is likely to be captured by those who could exert power (whose interests do not usually coincide with those of the majority).

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Consequently, although there are some areas of expertise, the knowledge-related characteristics of firms and PROs, and their interactions, have not developed consistently. For example, the literature agrees that firms' innovative capabilities are rather poor and the proportion of human resources in science and technology as a percentage of the population is low; in addition, there is a general perception that PRO-I interactions are weak (Cassiolato *et al.*, 2003; Cimoli, 2000; Dutrénit *et al.*, 2010a; López, 2007).[1] According to some authors, Latin American universities were traditionally fairly disconnected from (and usually opposed to) both, the government and industry (Arocena and Sutz, 2005), while others argue that linkages were based more on informal contacts than on formal bases, which have made their documentation and broad diffusion more difficult (Pirela *et al.*, 1991; Vessuri, 1998). Nevertheless, recent funding pressures in PROs, in conjunction with the diffusion of ideas that questioned the role of the State as the main pillar for scientific production, have promoted more active participation of the private sector in science and technology upgrading and have encouraged firms and PROs to interact with each other (Dasgupta and David, 1994; Etzkowitz *et al.*, 2005; Nelson, 2004; Slaughter and Leslie, 1997).

Worldwide, PRO-I interactions have become an important issue of policy interest to strengthen the NSI. Most of the research has focused either on the firms' perspective (Eom and Lee, 2009; Fontana *et al.*, 2006; Hanel and St-Pierre, 2006; Laursen and Salter, 2004; Rasiah and Govindaraju, 2009) or on the university perspective (Di Gregorio and Shane, 2003; Friedman and Silberman, 2003; Schartinger *et al.*, 2002; Tornquist and Kallsen, 1994). Few studies have looked at the determinants of PRO–I interactions taking the individual academic researcher as the unit of analysis (Agrawal and Henderson, 2002; Landry *et al.*, 2007; Suzigan *et al.*, 2009). In this paper we explore the perspective of both agents; an approach followed by very few authors (Lee, 2000; Bekkers and Bodas Freitas, 2008; Carayol, 2003; Eun, 2009; Intarakumnerd and Schiller, 2009; Joseph and Abraham, 2009).

Despite sharing the national organisational and institutional context, PROs and firms face different incentive frameworks to establish interactions for knowledge exchange (Foray and Steinmueller, 2003; Nelson, 1993). Thus, studies focusing on only one individual agent provide insights into different aspects of PRO-I interactions such as: drivers to connect, motivations, preferred channels of interactions, benefits etc., but are limited to informing policymakers because one perspective is always missing.

There is abundant empirical evidence to suggest that the process of knowledge transfer between PROs and industry occurs through multiple channels, such as human resources formation, open science, informal contacts, consulting relationships, joint and contract research projects, patenting and spin-offs. From the industry perspective, some authors argue that open science, property rights, human resources, collaborative R&D projects, and networking are considered to be amongst the most important (i.e. more frequently used with better results) channels of knowledge flow (Cohen *et al.*, 2002). From the academic perspective, differences were also found, for instance Meyer-Krahmer and Schmoch (1998) make a case that collaborative R&D is the most important form of interaction in some fields. Bekkers and Bodas Freitas (2008) found that the relative importance of the channels is similar amongst firms and academic researchers. However, researchers assign more importance to all the channels than do firms.

Channels have been classified in different ways, such as in terms of the degree of formality in the organisational agreements (Bonaccorsi and Piccaluga, 1994; Eun, 2009; Schartinger *et al.*, 2002; Vedovello, 1997), or the degree of articulation and personal communication between agents (Fritsch and Schwirten, 1999; Perkmann and Walsh, 2007). Some authors have claimed that the intensity of use of different forms of interaction is sector, field and/or technology specific (Bekkers and Freitas, 2008; Cohen *et al.*, 2002; Meyer-Krahmer and Schmoch, 1998; Schartinger *et al.*, 2002).

The literature has identified a set of benefits that may be obtained through PRO-I interactions. From the firms' perspective it was found that firms obtain a different perspective from which to solve their problems and in some cases perform product or process innovations, which would have been impossible without the interaction. They also benefit from highly skilled research teams, new human resources, and access to different approaches to problem solving

(Rosenberg and Nelson, 1994). For researchers, the benefits include: obtaining additional funding for their laboratories and exchanging knowledge (Meyer-Krahmer and Schmoch, 1998), securing funds for research assistants or for complementing their own salary, gaining insights for their own academic research, testing applications of a theory and supplementing funds for their own academic research (Fritsch and Schwirten, 1999; Lee, 2000) or acquiring a new perspective from which to approach industry problems by appropriately shaping the knowledge of the products (Hanel and St-Pierre, 2006).

Although there are reasons to believe that some channels of interaction may be more effective in driving specific types of benefits, very little research has been done in these lines.[2] This special issue is an attempt to fill this gap. We analyse the relationship between channels of PRO-I interactions and benefits in four Latin American countries (Argentina, Brazil, Costa Rica and Mexico) from the perspective of both agents (researchers and firms). In particular, following Arza (pp 473–484, this issue), we assess the relative effectiveness of channels of PRO-I interactions in triggering different benefits received by researchers and firms involved in these interactions. This information would be useful for policy-makers seeking to design policy selectively: it would be possible to select to support those channels that better suit targeted benefits.

The conceptual framework proposed by Arza (pp 473–484, this issue) argues that different motivations for firms and PROs to engage in interactions are better served by specific channels of interactions. Since expected benefits are to be related to the initial motivations that drove the interactions, the conceptual framework allows us to relate channels with benefits and also to assess them empirically.

Two main types of benefits for firms and for researchers were identified, as noted above, related to the early motivations for interacting.

Firms may interact to:

- Contribute to their short-term production activities: these benefits are oriented to solving short-term production problems (e.g. receiving advice for solving production problems, performing tests, helping with quality control etc.).
- Contribute to their long-term innovation strategies: these benefits are oriented to contributing to long-term innovation capabilities and outputs (e.g. augmenting firm's absorptive capabilities, finding partners for research activities which complement or substitute for firms' R&D etc.).

Researchers may interact to:

- Create intellectual outputs: those benefits related to long-term nurturing of the knowledge skills of PROs (finding inspiration for future scientific research, accessing ideas for new PRO-I collaboration projects, gaining reputation etc.).
- Contribute to their economic needs: those benefits related to accessing additional resources to solve short-term funding constraints (gaining access to research inputs, finding new sources of finance, sharing/hiring equipment/instruments available in PRO laboratories etc.).

The four channels of PRO-I interactions identified were:

- *Traditional:* This is related to traditional ways in which firms benefit from PRO activities (e.g. hiring recent graduates, conferences, publications). Knowledge flows mainly from PROs to firms and knowledge contents are defined by the conventional functions of academic institutions (e.g. teaching and researching). Personal interaction is not required.
- *Services:* This includes 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 PROs to firms. Personal interaction is usually on a short-term basis.
- *Commercial:* Interactions are motivated by an attempt to commercialise the scientific outcomes already produced by PROs (patents, technology licenses, spin-off companies, incubators etc.). Depending on the specific contractual agreement established and the extent to which researchers become involved in entrepreneurial or support activities, knowledge may flow in both directions. Personal contact is established at the beginning of the relationship. It may continue later depending on the specificities of the agreement.
- *Bi-directional:* This channel is motivated by long-term targets of knowledge creation by PROs and innovation strategies by firms (joint R&D projects, participation in networks, contract research, scientific-technological parks etc.). Both agents provide knowledge resources. Interaction is usually on a long-term basis.

The empirical evidence on which we base our analysis comes from original micro-data collected through surveys on firms and researchers within the framework of an international comparative project titled 'Interactions between universities and firms: searching for paths to support the changing role of universities in the South', developed under the umbrella of the 'Catching up' project. This project was sponsored by the IDRC and compares PRO-I interactions of 12 countries from Latin America, Asia and Africa. The questionnaires in both surveys were elaborated as a result of several interactions among all the national teams. The questionnaire sent to the firms draws on the Carnegie Mellon (Cohen *et al*., 2002) and the Yale (Levin *et al*., 1983) Surveys.[3]

The conceptual framework proposes that the traditional and the bi-directional channels were associated with long-term intellectual benefits for PROs[4]

while the bi-directional and the commercial channels were associated with long-term innovation benefits for firms. Thus, the bi-directional channel is proposed as the one which triggers longer-term benefits for both agents.

Based on country studies presented in this special issue (Arza and Vazquez, pp 499–511, Dutrénit *et al.*, pp 513–526, Fernandes *et al.*, pp 485–498; Orozco and Ruiz, pp 527–540), this paper discusses the results and extracts a set of features of PRO-I interactions, particularly related to the relationship between channels and benefits in these Latin American countries. We are aware that Latin America is a heterogeneous region; our research includes countries that differ in terms of size of the economy, level of development, sectoral specialisation etc. However, their PROs share quite similar patterns of evolution, and more importantly, similar policy guidelines regarding support for PRO-I interactions.

This paper is divided into five sections. After this introduction, the second section summarises some general characteristics of the evolution of PROs, firms and science and technology (S&T) policies that have affected the actual state of PRO-I interactions in Latin America. The third section analyses and compares across the four countries the relative effectiveness of different channels in driving specific benefits for firms and researchers. The fourth section presents a set of features of PRO-I interactions that emerge from the comparative analysis. The last section offers our final reflections on PRO-I interactions in the four Latin American countries.

Underlying factors in recent PRO-I interactions in Latin America

NSI in Latin American countries have largely been built from a top-down perspective, as a result of S&T policies based on a supply-push focus associated with the linear model of innovation. This was strengthened by the creation of S&T agencies in the 1970s. However, from the 1990s onwards, policies have slowly moved towards a more balanced supply-demand approach.

Universities differ across countries in relation to their origins. However, a common feature is that they were initially oriented to undergraduate teaching, and, gradually, as research activities became stronger, postgraduate studies were offered (starting in the second half of the 20th century). Thus, it was only recently that it became possible to connect teaching and research activities. These timid connections within universities trigger dissimilar connections to the outside world, in many cases based much more on informal linkages than on institutional contracts (Vessuri, 1998). Public research centres were created under this supply-push approach and focused on supporting some key sectors (e.g. coffee in Costa Rica, aeronautics and oil in Brazil, oil in Mexico, nuclear technology in Argentina, and agriculture in all countries) considered important by the policy-makers.

Firms, in turn, evolved in production systems with unclear incentives. In general, industrial policies failed to foster integration of productive chains and competitiveness. However, the incentives were not homogeneous across all firms. For instance, some sectors remained fairly protected (either naturally or through intervention) from international pressures and consequently firms operating in those activities manage to survive and sometimes to grow without engaging in technological learning or in building innovative capabilities. In contrast, liberalisation destroyed the incipient but yet decisive knowledge accumulation envisaged after several years of policy support under the import substitution industrialisation regimes in other sectors (e.g. machinery tools in Argentina, and process industries in Mexico). In addition, the ownership of the firms also matters as a source of heterogeneity in their competitiveness. Subsidiaries of multinational corporations, many of which have developed a strong presence in Latin America since the 1960s, impinged on the structure of the production system (Mexico and Costa Rica) or on its evolution (Brazil and Argentina). In most cases competitiveness relied on static comparative advantages that had driven subsidiary localisation in the first place (factor endowments and policy support). Sources for dynamic advantages (R&D and innovation) were absent, imported ready-to-use, or at a low level of the capability building process. Thus, without technologically active subsidiaries, the role of multinational companies in upgrading the NSI of these countries has been limited.[5]

If one were to compare the relative efficiency of PROs and firms in Latin America, then it seems fair to argue that the scientific production system has been more successful internationally than the technological production system. For example, worldwide publication of scientific papers is much higher than the participation in the world patents submitted to the US Patent and Trademark Office. Moreover, the increase in the scientific output observed in the last decade was not accompanied by an increase in applications for patents. Even though patents are only one measure of innovative dynamism, this suggests that the scientific side of the NSI has improved at a quicker pace than the business sector side.

Although, as said before, researchers in general and those working in universities in particular have traditionally been reluctant to interact with industry, this has been changing slightly in recent times. In fact, a shift towards positive perceptions of PRO-I interactions can be observed in researchers, the managements of PROs, and other agents, including policy-makers.

It should be noted that, despite relatively scarce PRO-I interactions, research pursued in PROs has been key for successful historical experiences in some industries in the countries analysed in this paper. For instance, Gutiérrez (1993) and León and Losada (2002) highlight the importance of research by PROs for agricultural technological upgrading in

Argentina; Suzigan and Albuquerque (2009) argue the importance of university research for the development of the aircraft, steel and agricultural industry in Brazil; and Casas *et al.* (2000) discuss the role of PROs in successful experiences in the chemical and other process industries in Mexico.

All those cases involved rather passive interactions of the traditional or services type, based on human resources formation, information access, training and other services rather than on intensive use of the bi-directional or commercial channels. In what follows we analyse the relative importance allocated by firms and researchers to different channels of interactions and we assess their effectiveness in driving long- and short-term benefits for both agents.

Comparative analysis of channels-benefits amongst countries and agents

This section compares the main empirical findings of the four countries using common datasets. The papers estimate the econometric models suggested by Arza (pp 473–484, this issue), which are presented below:

Researchers

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

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

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

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

Firms

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

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

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

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

These models relate four channels of interactions (included in vector Ch_i: traditional, commercial, services and bi-directional)[6] with two types of benefits for researchers (economic (*EB*) and intellectual (*IB*))[7], and two for firms (production (*PB*) and innovation (*InB*)). When data allowed, Heckman models that controlled for the selection bias of being linked were estimated.[8] Furthermore, all country teams agreed on similar proxies for these key variables (channels and benefits) and included other control variables to improve the overall fit of their models.

This section is divided into three parts. First, we compare descriptive findings on the 'importance' of using different channels for knowledge-related activities, as perceived by researchers and firms. Secondly, we provide a descriptive comparison of the 'importance' of the benefits obtained through PRO-I interactions, as perceived by firms and researchers. To normalise the country specificities all comparisons are based on the ranking of importance of different channels and different benefits within each country. As will be seen, firms and researchers in Brazil tend to be the most positive about all channels and benefits while firms and researchers in Argentina tend to be the most negative. Mexico and Costa Rica are intermediate cases. Finally, we compare the econometric findings of country papers based on the sign and significance of coefficients of key variables, especially on the relationship between channels and benefits.

Channels of interaction

There is one clear agreement by researchers and firms in all countries: the relative lack of importance of the commercial channel for all the forms of interaction that are grouped in it (see Tables 1 and 2). This result confirms what was found by other authors analysing developed countries (Agrawal and Henderson, 2002; Cohen *et al.*, 2002; D'Este and Patel, 2007; Meyer-Krahmer and Schmoch, 1998).

Another interesting common finding is the relative importance of informal interactions through conferences or other types of informal information exchange, as it was also found by Cohen *et al.* (2002), Meyer-Krahmer and Schmoch (1998) and and Fontana (2007). In addition, researchers of the four countries tend to assign higher importance to any channel than firms, as was also found by Bekkers and Bodas Freitas (2008) for another region.

Analysing important channels in the case of researchers, the agreements across countries are slightly weaker (see Tables 1 and 2). In Brazil and Costa Rica, they tend to prefer traditional channels (especially publications and conferences), while in Argentina they prefer the services channel (consultancy) and in Mexico the bi-directional channel (joint R&D).

Benefits from interaction

As can be seen in Table 3, researchers in all countries tend to mention intellectual benefits more often than economic benefits as the most important

Researchers and firms in all countries agree about the relative lack of importance of the commercial channel of interaction. This agrees with analysis of developed countries

Table 1. Importance of channels for researchers (% classified as moderately and very important)

Forms of interactions	Channel	Argentina		Brazil		Costa Rica		Mexico	
Joint or collaborative R&D	Bi-directional	38.2	4	70.6	5	62.3	4	61.0	1
Contract research	(*BCh*)	37.1	5	74.8	2	36.7	7	55.3	3
Networking with other agent		18.0	9	46.0	10	30.6	8	47.0	7
Science and/or technology parks		9.0	13	40.1	12	17.3	13	--	--
Incubators	Commercial	9.0	14	40.0	13	18.3	12	35.1	8
Patents	(*CCh*)	10.1	12	42.9	11	8.1	15	30.6	11
Technology licenses		13.5	10	38.6	14	22.4	11	29.9	13
Spin-off from PROs		6.7	15	37.1	15	15.3	14	25.7	14
Informal information exchange	Services (*SCh*)	44.9	2	66.0	6	82.6	1	57.7	2
Consulting		78.7	1	52.1	9	49.0	6	50.1	4
Training staff		29.2	6	70.9	4	61.2	5	48.8	5
Internships		--	--			29.6	9	32.7	10
Temporary personnel exchanges		12.4	11	53.1	8	--	--	--	--
Conferences and seminars	Traditional	43.8	3	74.3	3	73.1	3	48.6	6
Recently hired graduates	(*TCh*)	29.2	7	58.3	7	26.7	10	34.3	9
Publications		24.7	8	74.9	1	74.5	2	30.1	12

Source: Arza and Vazquez (2010), Fernandes *et al*. (2010), Orozco and Ruiz (2010) and Dutrénit *et al*. (2010b)

benefits triggered by interactions. In particular, researchers seem to be inspired by the interaction with firms to pursuing further research (either in collaboration with other partners or not), confirming results obtained by several authors (Fritsch and Schwirten, 1999; Lee, 2000).

Firms tend to connect to PROs for short-term problem solving rather than to gain insights for their long-term innovative strategies (see Table 4). This contrasts with the literature from developed countries that mostly focuses on channels related to new knowledge generation such as patents (Adams *et al.*, 2003; Arvanitis *et al.*, 2008; Cohen *et al.*, 2002). In Argentina, Brazil and Mexico, one of the benefits most frequently mentioned as important is performing tests, and in all countries, including Costa Rica, obtaining technological advice to solve production-related problems. Making earlier contact with students for possible future recruitment appears to be an important benefit for firms, particularly in Mexico. Nevertheless, in Brazil and Costa Rica firms pointed out benefits related to their innovation

Table 2. Importance of channels for firms (% classified as moderately and very important)

Forms of interactions	Channel	Argentina		Brazil		Costa Rica		Mexico	
Joint or collaborative R&D	Bi-directional	25.5	6	68.1	2	26.6	9	46.5	4
Contract research	(*BCh*)	23.5	7	54.6	6	29.0	5	37.8	8
Networking with other agent		15.3	9	48.5	8	28.2	8	34.5	9
Science and/or technology parks		12.2	11	36.5	9	25.0	10	–	–
Patents	Commercial	15.0	10	33.1	10	16.9	12	33.5	10
Technology licenses	(*CCh*)	16.4	8	32.8	11	29.0	7	30.8	11
Incubators		5.1	13	22.4	13	15.3	14	24.3	13
Spin-off from a PRO		2.0	15	15.3	15	13.7	15	10.8	14
Firm owned by PRO		2.5	14	15.3	14	16.1	13	–	–
Staff training	Services	–	–	–	–	–	–	52.6	1
Informal information exchange	(*SCh*)	51.0	1	61.3	4	57.3	1	41.9	6
Consultancy with individual researchers		26.6	5	52.1	7	29.0	6	40.3	7
Temporary personnel exchange		10.2	12	32.8	12	24.2	11	25.2*	12
Conferences and exhibitions	Traditional (*TCh*)	45.9	3	61.0	5	50.8	2	48.9	2
Recently hired graduates		26.9	4	62.9	3	41.1	4	48.9	3
Publications		47.3	2	69.6	1	41.1	3	45.3	5

Note: In case of Medxico, refers to 'Internships'
Source: Arza and Vazquez (2010), Fernandes *et al.* (2010), Orozco and Ruiz (2010) and Dutrénit *et al.* (2010b)

Table 3. Importance of benefits from interaction for researchers (% classified as moderately and very important)

Benefits	Type of benefit	Argentina		Brazil		Costa Rica		Mexico	
Inspiration for future scientific research	Intellectual	70.0	2	85.87	1	76.5	5	0.70	3
Share of knowledge/ information		75.0	1	81.79	2	89.8	2	0.66	4
Ideas for new PRO-I collaboration projects		66.0	3	81.59	3	87.8	3	0.73	1
New social networks		–	–	72.34	4	70,4	6	–	–
Reputation		56.0	5	70.65	5	92.9	1	0.65	5
Provision of research inputs	Economic	45.0	6	70.15	6	60.3	7	0.56	7
Financial resources		64.0	4	69.85	7	78.4	4	0.61	6
Share equipment/ instruments		35.0	7	53.93	8	48.9	8	0.73	2

Source: Arza and Vazquez (2010), Fernandes *et al.* (2010), Orozco and Ruiz (2010) and Dutrénit *et al.* (2010b)

activities. Brazilian firms seem to benefit from the transfer of technology from PROs, and Costa Rican firms claimed that by interacting they obtained information about novel trends in R&D.

Channels and benefits

One key contribution of this paper is the discussion of empirical findings of four Latin American countries based on similar econometric models presented above. Although there are country specificities, the main results in the relationship between channels and benefits are consistent across most countries. In what follows we summarise the results derived from the papers on Argentina (AR), Brazil (BR), Costa Rica (CR), and Mexico (MX) mentioned above (see Tables 5 and 6) about researchers and firms, respectively. For each type of benefit we specify the significance and signs of all channels of PRO-I interactions; and we also list control variables with significant coefficients included in the estimation under the column 'Other significant variables'. A '(−)' means a negative coefficient, otherwise the coefficient was positive.

Table 4. Importance of benefits from interaction for firms (% classified as moderately and very important)

Benefits	Type of benefit	Argentina		Brazil		Costa Rica		Mexico	
Augment firm's ability to find and absorb technological information	Innovation	18.0	7	57.4	7	51.0	4	40.0	5
Technology transfer from PROs		21.0	5	60.1	3	43.0	8	39.0	6
Contract research to contribute to firm's innovative activities (complementary)		–	–	58.3	5	48.0	6	39.0	7
Contract research that firms do not perform (substitute)		13.0	9	58.0	6	32.0	10	38.0	9
Obtain information about engineers or scientists and/or trends in R&D in field		17.0	8	47.2	8	52.0	2	37.0	10
Make earlier contact with students for future recruitment	Production	25.0	4	37.1	9	52.0	3	47.0	1
Perform tests necessary for products/processes		43.0	1	63.2	1	39.0	9	44.0	2
Obtain technological advice from researchers to solve production-related problems		30.0	3	59.5	4	62.0	1	43.0	3
Use resources available at PROs		20.0	6	61.7	2	50.0	5	40.0	4
Assistance with quality control		38.0	2	27.9	10	48.0	7	38.0	8

Source: Arza and Vazquez (2010), Fernandes *et al.* (2010), Orozco and Ruiz (2010) and Dutrénit *et al.* (2010b)

Table 5. Determinants of benefits for researchers: channels of interactions and other significant control variables

Country	Intellectual benefits					Economic benefits				
	Other significant variables	*TCh*	*SCh*	*CCh*	*BCh*	*TCh*	*SCh*	*CCh*	*BCh*	Other significant variables
AR	Female [gender***]		***	(-)**	***		***			
BR[1]	(-) Experience [(-) age***]	***	***	(-)***	***	***	***		***	(-) Experience [(-) age**]
CR			*				*		*	(-) Research field [(-) Research fields*]
MX	(-) Team experience [(-) team age*]	*		(-)***	**					Team experience [team age**]
	Team knowledge skills [human resources team*]									(-) Team knowledge skills [(-) HR team]**
	Knowledge skills [Master*, PhD*** base: graduate]									
	(-) Firms initiative [(-) firms initiative in collaboration*]									

Notes: *p ‹ 0.1; **p ‹ 0.05; ***p ‹ 0.01
Significant drivers are named by general concept they represent
Name of variable is given in square brackets. Variables are defined in Appendix to this paper
[1] Data for Brazil corresponds to interactions with universities
Source: Arza and Vazquez (2010), Fernandes et al. (2010), Orozco and Ruiz (2010) and Dutrénit et al. (2010b)

On the one hand, as can be seen in Table 5, researchers received intellectual benefits mainly through the services (AR, BR, CR) and the bi-directional (AR, BR, MX) channels, while the commercial channel seems to have a negatively effect on the creation of intellectual benefits for researchers (AR, BR, MX). In turn, economic benefits are mainly driven by the services channel (AR, BR, CR). Some country specificities may be highlighted. The bi-directional channel was also significant for obtaining economic benefits in Brazil and Costa Rica. In Costa Rica, the bi-directional channel was important for obtaining economic rather than intellectual benefits. In contrast, in Mexico no channel was found to be an important driving force in obtaining economic benefits for researchers.

On the other hand, Table 6 shows that firms obtain benefits related to their production activities mainly through the traditional and bi-directional channels in all the countries. These channels also

Table 6. Determinants of benefits for firms: channels of interactions and other significant control variables

Country	Production benefit					Innovation benefit				
	Other significant variables	*TCh*	*SCh*	*CCh*	*BCh*	*TCh*	*SCh*	*CCh*	*BCh*	Other significant variables
AR	Sector innovativeness [sector_ia*]	**			**	**			***	Sector innovativeness [sector_ia*]
	(-) Short-term interaction [(-) length_1***]									(-) Short-term interaction [(-) lengh_1***]
	(-) Size [(-) decil_workers*]									Innovativeness [inno_prodproc]**
BR	(-) Public support [(-) network ac gov***]	**	**		**	**			***	(-) Public support [(-) network ac gov***]
	(-) Sector innovativeness [(-) sector ia***]									(-) Innovativeness [(-) inn_prodproc*]
CR	(-) Size [(-) Decil_obreros***]	*			*	*	*		*	(-) Size [(-) Decil_obreros**]
	Public support [Fin-pub_ai**]									
MX	(-) Public support [(-) Fiscal incentives for R&D**]	*	*		**		*		**	Use of private information [Openness F2**]
	Innovativeness [HR R&D**]									(-) Public support [(-) Fiscal incentives for R&D*]
	Innovativeness [formalise R&D**]									Innovativeness [HR R&D**]
	(-) Use of open information [(-) Openness F1 ***]									

Notes: *p ‹ 0.1; **p ‹ 0.05; ***p ‹ 0.01
Significant drivers are named by general concept they represent
Name of variable is given in square brackets. Variables are defined in Appendix to this paper

work as important drivers of benefits related to innovation activities; the traditional channel was significant for Argentina, Brazil and Costa Rica, and the bi-directional channel was significant in all countries. Moreover, the services channel was also a key driver of production benefits (BR, MX) and of innovation benefits (CR, MX).

Referring to control variables, key concepts were included in all the country cases to improve the fit of their models. These control variables include: proxies to a set of selected concepts, such as researchers' and team's characteristics, type of research, motivations for the case of researchers, and firms' characteristics, firms' strategy (innovativeness, networking and access to information) and public support for R&D activities for the case of firms. Since the concepts included and the way they were measured differ across countries, it is not possible to establish strict comparisons.

Features of PRO-I interactions

Based on the evidence of the four Latin American countries, this section highlights a set of features that emerge from the descriptive statistics and econometric findings.

- The channels of interactions considered more important by researchers and firms in all countries are the services and the traditional channels. In particular, agents in all countries seem to prefer the informal forms of interaction and those involving the training of human resources.
- The most important benefits of PRO-I interactions for researchers are related to the possibility of pursuing further research in the future (i.e. intellectual), while those for firms are related to their contribution to short-term production activities rather than to long-term innovation activities.
- The bi-directional and the services channels are the most effective in triggering intellectual benefits for researchers. However, when PRO-I interactions use the commercial channel the intellectual benefits are reduced.
- PRO-I interactions that use the bi-directional and the traditional channels are the most effective in triggering both types of firms' benefits – production and innovation.

Conclusion

This paper has explored the effectiveness of channels of PRO-I interaction on benefits for researchers and firms in four Latin American countries. It has drawn on a vast literature about PRO-I interaction, mostly built on evidence from developed countries. This literature pays more attention to the channels associated with knowledge creation than those channels that may impact other dimensions either of business performance or activities by researchers. The latter are particularly important for firms that do little or no R&D, like most Latin American firms. This paper found that different channels of PRO-I interactions have different level of effectiveness in driving different types of benefits.

The four countries present idiosyncrasies, such as differences in terms of size, competitiveness, policy mix etc. However, they share similar characteristics in relation to the origins and evolution of the PROs. Moreover, they went through similar macroeconomic regimes in similar periods (import substitution from the 1940s to the 1960s, and liberalisation during the period from the 1970s to the 1990s). Finally, the intellectual and political discussions on the benefits of promoting PRO-I interactions came across in all countries in recent years, and in all of them policy changes were pursued accordingly. As a result, PRO-I interactions, although still weak by international standards, have increased notably in the 1990s. Other Latin American countries also share these characteristics. In this sense, even though our claims refer to Argentina, Brazil, Costa Rica and Mexico, they can give insights about Latin America.

Our results show that researchers were quite positive in relation to their interactions with the private sector. On average, they were more positive than firms. This finding has been replicated elsewhere (Bekkers and Bodas Freitas, 2008).

The importance of diverse channels of interactions differed across countries. However, there was agreement that the commercial channel (i.e. patents, incubators, spin-off etc.) was considered to be the least important by both agents. Papers based on developed countries came to the same result (Cohen *et al.*, 2002; D'Este and Patel, 2007), and this pattern seems to be reproduced in general in developing countries. However, Korea, which is an emerging economy, shows the opposite pattern (Eom and Lee, 2009).

Interestingly, researchers claim that the main benefits they received from their interactions were related to their intellectual activities, mainly to gain inspiration for further research in the future. This confirms results obtained by other authors in developed countries (Fritsch and Schwirten, 1999; Lee, 2000). Latin American authors argue that researchers have been pushed to interact with the private sector due to budget pressures (Arocena and Sutz, 2005), but according to our results it can be argued that once connected to firms they obtain intellectual benefits. The bi-directional and the services channel are the most effective in driving intellectual benefits in most countries. In keeping with that literature, we find that economic benefits were mostly associated with those PRO-I interactions that used the services channel. Since PROs in Latin America are largely underfinanced and given that the services channel drives economic benefits, the positive effect that this channel also exerts on intellectual benefits must be controlled by the increase in budget, as suggested by Defazio *et al* (2009).

Economic benefits were mostly associated with those PRO-I interactions that used the services channel. PROs in Latin America are largely underfinanced and need more support

We find that the commercial channel drives negative intellectual benefits for researchers. This result is worrying. Intellectual benefits are mainly associated with the opportunities opened by PRO-I interactions in terms of future research. In addition, given that the commercial channel implies by definition a commercialisation of already produced knowledge outputs, the negative sign on intellectual benefits can be interpreted as a reduction in opportunities for further research due to the privatisation of otherwise public knowledge outputs. This raises concerns about the risks of privatisation of publicly created knowledge in PRO-I interactions and may affect research downstream (i.e. research that builds on previous knowledge) and that of future generations. However, an alternative interpretation of the negative intellectual benefits related to the commercial channel could be that the work done is repetitive, uninteresting, and in this sense is not a real process of learning. This issue requires further research.

In contrast to researchers, firms obtain somewhat short-term benefits from PRO-I interactions. We find that, in general, firms claim that PRO-I interactions contribute to their short-term production activities rather than to long-term innovation activities. Firms tend to use the traditional channel (i.e. graduates, publications, conferences) more often than any other channel. However, it is the bi-directional channel (i.e. the channel that includes forms of interactions through which knowledge flows in both directions, e.g. joint research) that drives better benefits, such as those related to long-term innovation strategies. Somehow this channel may be the most appropriate for transmitting tacit knowledge through personal interaction on a long-term basis. Given that tacit knowledge usually conveys more novelty than codified knowledge, the outputs triggered by this channel of interaction could be more path-breaking in terms of solving technological bottlenecks. This may explain the broad agreement among firms in all countries regarding the effectiveness of the bi-directional channel.

Finally, from the comparison of researchers and firms it emerges that the former seek and obtain long-term benefits while the latter seek and mostly obtain short-term benefits. This suggests that the nature of knowledge appropriated seems to differ for the two types of agents. Several factors may explain this difference in behaviour. It has been claimed that the average firm in Latin America tends to adopt rather defensive practices, the normal reaction of agents operating in highly uncertain contexts (Arza, 2005; Cimoli and Katz, 2003; Katz, 2004). Although it has been affected by a similar environment, the career path of researchers is somehow more stable than, say, an R&D manager in a firm. This may explain the differences in attitude. However, other differences may stem from the skill-related characteristics. The ability of an agent to appropriate knowledge from PRO-I interactions (as from any external source) is associated with its own knowledge capabilities. It is likely that the average researcher is better positioned to expect longer-term benefits than the average firm. In fact, the evolution in the worldwide participation of the main outputs of both agents (papers and patents) suggests the existence of different strengths of knowledge capabilities (e.g. participation in papers is much higher that in patents and has grown at a higher rate). Thus, it seems that the scientific capabilities of PROs have been built at a quicker pace than innovation capabilities by firms. This may have an impact on the nature of PRO-I interactions and the strength of the NSI.

Finally, referring to some policy implications, the negative effects of the commercial channel on intellectual benefits, raise issues of concern about the 'tragedy of the scientific commons' (Nelson, 2004), which may turn up if PRO-I interactions imply a privatisation of knowledge that formerly belong to the stock of public knowledge. This may have clear socioeconomic consequences and it is particularly relevant in developing countries where large firms have better access to intellectual property rights mechanisms than do many PROs.

The importance of recently hired graduates from the firms' perspective suggests that they could be seen as an important interface between researchers and firms. The literature based on developed countries usually highlights the importance of this form of interaction. However, authors tend to focus on knowledge generation related interaction and pay less attention to this form of interactions. Our results call for new science, technology and innovation policies oriented to working with undergraduates as a way to foster changes in firms' behaviour towards innovation activities and better PRO-I interactions, i.e. strengthening the bi-directional channel.

Even though policy-makers have recently been particularly concerned about fostering knowledge transfer through patents (which are part of the commercial channels in our framework), evidence shows that this is neither an important form of interaction in developed countries nor in Latin American countries, therefore emphasis on fostering patenting activity does not seem to be the most efficient way to strengthening PRO-I interactions or the articulation between the supply and demand of knowledge.

Appendix. Definitions of variables

	Variables	Type of data	Definition	General concept (specific concept)
			Researchers	
Argentina	Gender	Dummy	1 = female 0 = male	Researchers' characteristics (female)
Brazil	Age	Index	Researcher's quadratic age (i.e. squared distance to sample mean)	Researchers' characteristics (experience)
Costa Rica	Research fields	Ordinal	Depending on research field, it takes values: 0.2 = physics and math; 0.4 = chemistry and biology; 0.6 = medicine; 0.8 = biotechnology and agronomy; 1 = engineering and design.	Type of research (field)
Mexico	Master	Two dummy variables	Researcher's degree, Master = 1, PhD = 1, (base category: graduate)	Researchers' characteristics (knowledge skills)
	PhD			
	Age of team	Continuous	Years from creation of team	Researchers' characteristics (team experience)
	Human resources team	Continuous	Number of members in research team according to their skills,	Researchers' characteristics (team knowledge skills)
	Firm's initiative of collaboration	Dummy	If firm takes initiative = 1; Researchers' initiative = 0	Motivation (firms' initiative)
			Firms	
Argentina	decile_workers	Ordinal	Deciles based on employment for full sample	Firms' characteristics (size)
	sector ia	Continuous	Total expenditures in innovative activities over sales in each sector (2 digits ISIC) according to full sample	Firms' characteristics (sector technological intensity)
	length_1	Dummy	1 = interaction lasted less than one year	Strategy (short-term interaction)
	inno_prodproc	Dummy	1 = firm obtained new product and new process	Strategy (innovativeness)
Brazil	network ac gov	Dummy	1 = firm receives public funds to finance R&D activities	Public support
	sector ia	Continuous	Percentage spent on R&D in sector in 2009	Firms' characteristics (sector technological intensity)
	inn_prodproc	Dummy	1 = firm achieved innovations in products and processes	Strategy (innovativeness)
Costa Rica	decil_obreros	Ordinal	Deciles based on employment for full sample	Firms' characteristics (size)
	fin-pub_ai	Dummy	1 = firm receives public funds to finance its innovative activities	Public support
Mexico	openness F1	Factor loads	Strategy to access to open information	Strategy (open information)
	openness F2	Factor loads	Strategy to access to information through consulting and research projects with other firms	Strategy (private information)
	openness F4	Factor loads	Strategy to access to information through suppliers	Strategy (networking)
	fiscal incentives for R&D	Dummy	1 = firm benefited from fiscal incentives for R&D	Public support
	HR R&D	Continuous	Human resources in R&D as % of total employment	Strategy (innovativeness)
	formalise R&D	Dummy	Formal and continuous innovative activities = 1; Otherwise = 0	Strategy (innovativeness)

Notes: Only variables with significant coefficients in any of the estimated models are listed
Source: Arza and Vazquez (2010), Fernandes *et al*. (2010), Orozco and Ruiz (2010) and Dutrénit *et al*. (2010b)

Notes

1. The same pattern is described by Lorentzen (2009), Lall and Pietrobelli (2002) and Muchie *et al.* (2003) with reference to African countries.
2. Some exceptions are Wright *et al.* (2008), Adams *et al.* (2003) and Arvanitis *et al.* (2008).
3. See results of our colleagues from other regions: Kruss (2009) and Adeoti *et al.* (2010) for studies on African countries, and the special issue of the *Seoul Journal of Economics* (**22**(4), December 2009) for Asian studies.
4. Although the framework was developed for agents defined at institutional level (firms and PROs), in the empirical investigations we need to rely on data for firms and for individual researchers.
5. See Marin and Arza (2009) for a literature review about the role of multinational corporations on the NSI in developing countries and Dutrénit and Vera-Cruz (2007) on evidence related to building R&D capabilities of subsidiaries in Mexico.
6. Tables 1 and 2 list the forms of interactions that are included in our classification of the four channels. Researchers and firms had to allocate a value in the range 1–4 according to how 'important' they perceived those forms of interactions to be for their knowledge activities. To estimate the four channels we average the values of all forms classified under each of them and normalise to a 0–1 scale.
7. Tables 3 and 4 list the benefits as they were asked to researchers and firms, respectively. They had to assess their importance on a 1–4 scale. Benefits were classified into the above-mentioned groups of benefits (economic and intellectual for researchers, and production and innovation for firms), whose estimation result from calculating the mean values of benefits included in each group, later normalised to a 0–1 scale.

8. Argentina and Mexico have data on linked and unlinked firms and researchers and estimated Heckman models in both cases. Brazil only had data on linked firms and researchers and had to rely on an ordinary least squares (OLS) estimation. Costa Rica estimated Heckman models using data on firms, but OLS models using data on researchers (since they only have information about linked researchers).

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