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Firms' linkages with public research organisations in Argentina: Drivers, perceptions and behaviours

Valeria Arza [a,*], Andrés López [b]

[a] National Council for Science and Technology Research (CONICET), Centre of Studies for the Transformation (CENIT), Callao 796 6to piso (1023) Buenos Aires, Argentina
[b] Centre of Studies for the Transformation (CENIT), Argentina

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ABSTRACT

This paper analyses firms' drivers for linking to public research organisations (PRO) (first goal) and compares perceptions and behaviours of linked vs. unlinked firms (second goal). We used an original firm database constructed from a representative survey with information for linked and unlinked firms for year 2005 in Argentina. Drivers were estimated using a Probit model, while differences in perceptions and behaviours between linked and unlinked firms were assessed with propensity score matching techniques. For our first goal we found that (i) firms' knowledge bases were not drivers for linking to PRO and (ii) networking capabilities matter but there is a substitution effect between interacting with PRO and interacting with other economic agents in the market when firms aim at exchanging information rather than doing joint research. These findings may imply that current linkages are not exploiting properly their knowledge potential; it may be worth designing a division of labour among PRO in their functions in PRO–industry interactions. For our second goal: we found that (i) linked firms invest more in innovative activities; (ii) they are more prone to patenting; (iii) both groups of firms value similarly PRO research outputs available at arm length (i.e. without direct linking). Given the asymmetric development on appropriability tools between PRO and firms and the fact that all firms benefit from PRO research outputs, the higher predisposition of linked firms towards patenting, suggests that special attention should be placed at analysing the risks of a private appropriation of publicly created knowledge.

1. Introduction

Universities and public research institutes (hereafter public research organisations, PRO) have a key role in the creation and diffusion of knowledge via traditional activities, such as teaching and research (Dasgupta and David, 1994; Nelson, 2004; Pavitt, 2001). During the last decades and as a response to specific demands from the industry, to PRO's funding needs and to policy recommendations by international multilateral organisations, new activities that involve linkages with the private sector have emerged in many developing countries.

However, most of the existent literature on PRO–industry linkages was produced in the context of developed countries. This is worrisome since the structural characteristics of agents and their relationships in developing countries are markedly different. For example, based on the literature on regional clusters and industrial districts, which emphasises the role of universities as drivers for technological upgrading in their region, policy makers in developing countries have gone through frustrating experiences when trying to imitate successful examples from developed countries. In fact, linkages between PRO and firms in developing countries are much more related to the provision of specific services (e.g. testing, monitoring and consultancy) than to research or entrepreneurship (e.g. Arocena and Sutz, 2005; Dutrénit and Arza, 2010; Kruss, 2006; López and Orlicki, 2007; Ojewale et al., 2001; Vega-Jurado et al., 2007). The particular characteristics adopted by PRO–industry interactions in developing countries justify the need of specific research based on the experience of these countries.

In Argentina there are very few academic studies available related to the process of knowledge creation and diffusion in PRO, and even less that explicitly research about private–public interactions (e.g. Arza and Vazquez, 2010; Chudnovsky and López, 1996; García de Fanelli, 1993a, b, 1994; Llomovatte et al., 2006; Tenti Fanfani, 1993). The majority of those few papers related to the interaction between firms and PRO are based on case-studies, which either study the impact of linkages on firms' innovative capabilities (e.g. Lugones and Lugones, 2004; Moori-Koenig and Yoguel, 1998; Yoguel and López, 2001) or analyse the interaction

* Corresponding author. Tel./fax: +54 11 4815 1310.
E-mail addresses: varza@fund-cenit.org.ar (V. Arza), anlopez@fund-cenit.org.ar (A. López).

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dynamics from the point of view of the PRO (e.g. Bisang et al., 1995; Dávila, 2006; Estébanez, 1996; Juarros, 2006; Riquelme, 2008). To the best of our knowledge, there are not studies that compare the knowledge activities of firms that interact against those that do not interact with PRO using robust statistical procedures.

Given this relative scarcity of systematic research on relations between PRO and firms in Argentina and their potential for improving the National Systems of Innovation (NSI), we intend to conduct a study of an exploratory nature that allows us to understand the drivers of interactions and the differences in perception and behaviour between linked and unlinked firms. More specifically, on the one hand, we identify micro and meso determinants of interacting with PRO and motivations and obstacles for the interactions; and, on the other hand, we discuss what is different about linked firms in what respect to their innovative and financial behaviour and their perceptions about PRO outcomes and roles. Since we will provide a comprehensive mapping of the characteristic of interactive against non-interactive firms, we believe this paper will be particularly useful for policy makers in the area.

We use an original and representative dataset especially produced for this project. We follow a thorough methodology that allows us to control for biases that may emerge when setting cross-section comparisons. Our first research goal is about the determinants of linking and it is achieved by estimating a Probit model on the probability of linking. The second research goal refers to the behaviours and perceptions of firms that interact with PRO as opposed to similar but non-interactive firms and it is achieved using propensity score matching techniques.

The paper is divided into six more sections besides this introduction. Next section briefly discusses the international literature on PRO-firm linkages. The third section presents the strategy of data collection and discusses the main sample characteristics. The fourth section presents the methodology in which we discuss the propensity score matching techniques. The fifth section discusses the main determinants of interacting and therefore assesses our first research goal. The sixth section examines the empirical evidence to compare linked and unlinked firms, tackling the second research goal. Finally, last section discusses the conclusions and the main guidelines for policy making.

2. Conceptual framework and research goal

The traditional division of labour between PRO doing basic research and industry focusing on applied research seeking to convert scientific knowledge into usable technologies, which constitute the basic assumption of the linear model of innovation, has been largely questioned since the early 1990s.

On the one hand, it became clearer that many fields of research only advance scientifically in the context of application (Nelson, 2004; Rosenberg and Nelson, 1994). Therefore, basic research could not be separated from applied research. Moreover, not only the knowledge required for scientific progress became ever more multidisciplinary but also technological change speeded up. This redounded in larger demands on R&D investment from multiple players.

On the other hand, the liberal ideology questioned the role of the State as the main founder of science and promoted a more active participation of the private sector as a key agent and guide of research activities (Dasgupta and David, 1994; Etzkowitz et al., 2005; Nelson, 2004; Slaughter and Leslie, 1997). The emergence and expansion of venture capital and the widening of intellectual property rights, which accompanied this process, made entrepreneurial and commercial activities fairly attractive for some researchers, especially in developed countries.

Different conceptual frameworks emerged in the literature as a consequence of these changes, aiming at understanding the way scientific and technological knowledge should be produced and supported.

The first one directly tackling the change in the way knowledge was being produced was proposed by Gibbons et al. (1994). This framework claimed that knowledge production changed from the cognitive context governed by the academic interests of a disciplinary community (Mode 1) to a broader social and economic context of application of knowledge, which intends to be useful and usually involves more than one discipline and more than one community (Mode 2).

Later, Etzkowitz and Leydesdorff (1997) put forward the concept of the 'Triple Helix'. This framework claimed that innovation increasingly takes place in a knowledge infrastructure where three spheres (University, Industry and Government) are overlapped and taking the traditional roles of each other (the so-called "Triple Helix"). Since there is no a-priory synchronisation of participants, puzzles might be generated but they would be solved within the network dynamics. The policy recommendation, therefore, is to support the creation of networks and to make institutions as permeable as possible so they could freely take the role of each other. More specifically, the Triple Helix perspective supports the so-called "third mission of universities" – beyond teaching and research – and highlights the benefits associated to a more direct interaction and contribution to the industry.

Moreover, the literature of NSI was also very critical of the linear model of innovation. This literature places firms as central agents of innovation; but it claims that a necessary condition for successful innovative performance at country level is dependent on the development of a system of relationships between all organisations so as to allow a broad exchange of knowledge (Lundvall, 1992; Nelson, 1993). PRO and their interactions with the private sector play a central role in the creation and diffusion of knowledge in any system of innovation (Charles, 2003; Cooke, 2001). This is due to many reasons:

Firstly, of course, universities train graduates who are then employed and who contribute to innovative activities within the private sector. This occurs even if universities do not strategically orient their research and teaching programs to topics considered relevant by the industry.

Secondly, PRO renew the stock of scientific knowledge in a country. All users of scientific and technological knowledge need to build capabilities to assimilate and exploit different sources of knowledge. These capabilities are developed in a continuous, open minded and curiosity led learning process, which justifies public support for basic scientific research even in developing countries. However, as said above, many fields of research need to draw on applied knowledge to advance in scientific developments. In this sense the production of knowledge by PRO becomes more dynamic when interacting with firms due to challenges created in the resolution of specific production problems. This is especially true for the fields of research that the literature located in the 'Pasteur's Quadrant' (Stokes, 1997), which advance by doing basic and applied research simultaneously (e.g. all types of engineering, biotechnology, metallurgy, computer science, etc.).

Thirdly, the specific problems of industry are often so complex that require a combination of technologies that no individual firm could develop individually but that could well be generated from the pool of knowledge and resources created by the PRO (Patel and Pavitt, 1995). Some of these resources are new laboratory tools and analytical methodologies that constitute fundamentals inputs for the industry (Rosenberg, 1992). Moreover, PRO also

produce knowledge related to the economic and social context where firms sell and produce, which could determine the final success of any innovation process (Fritsch and Schwirten, 1999).

Most of the theoretical and empirical research on the relationship between PRO and firms has been done in the context of developed economies (e.g. Acworth, 2008; Boardman, 2008; Craig Boardman and Ponomariov, 2009; Etzkowitz and Leydesdorff, 1997; Loof and Brostrom, 2008; Mansfield, 1998; Motohashi, 2005, etc.). However, the requirements for developing countries to upgrade their NSI are different from those in developed countries (Mazzoleni and Nelson, 2007), as are their PRO–industry interactions (see Arza, 2010, for a discussion).

First, the socio-economic needs and therefore the policy strategies are different: unlike what happens in developed countries, large fractions of the population of developing countries live in conditions of poverty or indigence. Also, income distribution is highly unequal and education and health systems are deficient, perpetuating inequality. In addition, pollution is distressing in developing countries, which is largely explained by the use of outdated and polluting production technologies with no resources for environmental remediation. All these create specific demands to PRO, which are not necessarily comparable with the demands economy activity puts forward to PRO in developed countries.

Second, both PRO and firms in developing countries have specific and distinctive characteristics to their counterparts in developed countries. In Argentina, for example, the historical evolution of scientific production by PRO was once – and in certain fields still is – outstanding (e.g. three Argentinean scientists working in Argentinean PRO won Nobel Prizes). Notwithstanding scientific quality, the most notable feature of the science and technology system is policy inconsistency over time and lack of persistence in the roles assigned to the PRO as key agents for development (López, 2007). In this context, the promotion of interactions between PRO and firms, although intensified in recent decades, was not part of a national plan for science and technology development, but was rather the result of isolated policy instruments.

Similarly, the average technological dynamism of firms in developing countries is not comparable to their counterparts in developed countries. PRO–industry interactions need proactive knowledge seeking strategies in the industry to be effective (Mazzoleni and Nelson, 2007), since absorptive capabilities are required to exploit external sources of knowledge (Cohen and Levinthal, 1990) and also to diffuse the knowledge received from the PRO to other agents in the local system (Giuliani and Arza, 2009). In fact, the literature on linkages between PRO and firms in Latin America and in other developing countries often claims that one important limitation for a wide diffusion of linkages is the lack of demand for sophisticated technological knowledge from the industry (Vega-Jurado et al., 2007) or, at least, poor demand for *domestic* sources of knowledge—firms continue to depend on *foreign* technologies (Kroll and Schiller, 2010). The fact that innovative activities in developing countries are mostly adaptive may also contribute to explain the lack interactions aiming at original research. In the same vein, other authors note that the productive structure in Latin America is rather poor in the use of knowledge assets and therefore draws less from PRO—which, in turn, finds few opportunities for applied research in fields of the Pasteur's quadrant (e.g. Arocena and Sutz, 2005; Casas et al., 2000).

In sum, the small literature on PRO–industry interactions in developing countries highlights that these interactions are governed by idiosyncratic elements, which justifies the need for more specific research on drivers and benefits of PRO–industry interactions in developing countries. Recently, some research outputs from an IDRC project attempted to fill this gap (see two Special Issues: for Latin America in Science and Public Policy, 2010, Vol. 37, No. 7 and for Asia in the Seoul Journal of Economics, 2009, Vol. 22, No. 4. See also Kruss, 2009 for African studies).

In the case of Argentina, this is the first study that attempts to investigate the firms' determinants for linking (in Section 5) and to assess differences in behaviour and perceptions between linked firms against those that do not interact with PRO (in Section 6). More specifically, we will assess whether firms that connect to PRO are more or less innovative than firms that do not, tend to patent more than their counterparts, whether they have different access to funds for innovation and whether they value differently the research outputs from PRO. All these elements, we believe, will be very informative for science and technology policy and in the Conclusions (Section 7) we present some implications in this sense that are derived from this research. The next two sections present the data (Section 3) and the methodology (Section 4).

3. Data collection and sample characteristics

3.1. Data collection

This paper is based on information from the National Innovation Survey (hereafter *The Survey 2006*) whose fieldwork was carried out in December 2007 and managed by the National Institute of Statistics and Censuses (INDEC) (see INDEC, 2008). The sample was designed so as to be representative of the Argentinean manufacturing sector (2055 firms were included in the original sample). The response rate was 73% (1496 firms answered the form).

In order to pursue this research, an especial section on PRO–industry interactions was included in the Survey and sent to 590 firms that had declared to have interactions with PRO in the innovation survey for the previous year (*The Survey 2005*). They represented 35% of the total number of firms included in *The Survey 2005*. The response rate to this section was 60% (354 firms).

The definition of interactions was very broad; it ranged from joint R&D projects to informal information exchange. Organisations included as PRO are: Universities, Public Research Institutes (for industry and agriculture) and other government organisations for science and technology. Although universities and public research institutes differ in their mission within the NSI, in this paper they are taken together because in Argentina most researchers within these organisations formally belong to the same institutional framework and receive common incentives to interact with the private sector (i.e. they may be physically located at universities or public institutes but, in general, they have a common institutional affiliation at the National Council of Scientific and Technical Research. Moreover, project-based funds in either case are offered under the umbrella of the National Agency for the Promotion of Science and Technology).

Besides, another section with questions about PRO–industry interactions was sent to a control group of firms that did not have interactions with PRO in 2005. This control group was built taken into account the size and sector characteristics of linked firms. This form was sent to 384 firms and the response rate was 62% (238 firms).

3.2. Main descriptive statistics

In this section we present the main sample characteristics of the data used in the analyses. All variables to be analysed in this paper are listed and fully described in the Appendix. Unless otherwise stated, all data in this paper refers to year 2005.

Table 1 classifies firms in the sample according to their size: small (less than 40 employees), medium (less than 116 employees) and big (more than 116 employees) using information for 2005. It shows that a minority of linked firms are small, consequently that was also the case for control firms that were selected to match the sector and size characteristics of linked firms. In comparison to the size distribution of the full sample, there is an overrepresentation of big firms among linked firms.

Table 2, in turn, organises firms according to their sector affiliation. The last column in the table relates the proportion of firms per sector among linked firms with the proportion of firms per sector in the full sample. Expectedly, the sectors in which firms are particularly likely to be linked to PRO are known to be knowledge based sectors (i.e. chemicals (24), machinery (29) and electrical machinery (31)). We excluded sector 16 (tobacco products) from this comment because *The Survey* gathers information from very few tobacco firms.

Table 3 presents a matrix that relates sectors with fields of research for linked firms and it is inspired in Cohen et al. (2002). Cells inform the percentage of firms per sector that answered that each field of research was moderately or highly important for innovation activities during the last 10 years. Reading from the whole sample of linked firms (all sectors) the most important fields of research are (in order of importance) industrial design, chemical engineering, mechanical engineering and engineering of material and metallurgy.

Table 1
Sample characteristics in terms of size of linked and control firms in 2005.
Source: The Survey 2005 and The Survey 2006.

	N	Size			
		Small (%)	Medium (%)	Big (%)	Total (%)
Linked	355	16	27	56	100
Control	238	21	36	43	100
Full sample 2005	1675	30	30	40	100

The association of sectors to the fields of research works more or less as expected. For example, sector 24 (chemical industry) – in comparison to all linked firms – gives predominant importance to chemical engineering, chemistry, biology, physics, medicine and veterinary; sector 29 (general machinery), to industrial design, mechanical engineering, engineering of material and metallurgy, electrical engineering, physics, mining engineering and mathematics; sector 31 (electrical machinery), to industrial design, mechanical engineering and electrical engineering. Another relevant sector that we may mention is 15 (food products), which gives particular importance to food science and technology, agronomy, biology, veterinary, chemical engineering and chemistry.

Table 4 classifies linked and control firms according to different indicators of innovativeness. It is striking the large number of firms that consider themselves innovative. Around 64% of our sample (including linked and control firms) claims to have introduced new (or have improved significantly) processes or products. We believe this percentage is over-represented, highlighting the subjective nature of these kinds of indicators. For example, 16% of innovative firms have not spent anything on in-house innovative activities. In general, linked firms seem to be more innovative, especially in processes. However, Table 4 does not totally control for relevant variables that may affect linkages and innovativeness. This will be done later in Section 6.

Table 5 presents the importance of different modes of interaction as stated by linked firms. The options presented in the table comprise all options available in the questionnaire. The importance allocated to different modes, which in the questionnaire ranked from 1 to 4, was re-scaled to 0.25–1 by dividing the original answers by 4. The same normalisation was done in all tables that follow.

The most common mode of interaction is informal information exchange, followed closely by publications and conferences. All the other modes of interaction are much less frequent. In general, it can be said that traditional modes of interactions such as publications, conferences and training graduates are the most important ones, followed by modes related to service provision

Table 2
Sample characteristics in terms sectors (ISIC Rev 3, 2 digits).
Source: The Survey 2005 and The Survey 2006.

	Control firms (%)	Linked firms (%)	Full sample 2005 (%)	% of linked/ % of full sample
	A	B	C	B/C
15 Manufacture of food products and beverages	16.4	24.2	22.0	1.10
16 Manufacture of tobacco products	0.0	1.4	0.5	2.95
17 Manufacture of textiles	7.6	4.2	8.4	0.50
18 Manufacture of wearing apparel; dressing and dyeing of fur	1.3	2.8	2.7	1.03
19 Tanning and dressing of leather; luggage, handbags, saddlery, footwear, etc	2.9	2.3	2.3	0.97
20 Manufacture of wood and of products of wood and cork, except furniture	2.1	2.3	2.4	0.92
21 Manufacture of paper and paper products	5.5	1.7	2.9	0.59
22 Publishing, printing and reproduction of recorded media	3.8	1.1	5.1	0.22
23 Manufacture of coke, refined petroleum products and nuclear fuel	1.3	0.6	0.8	0.73
24 Manufacture of chemicals and chemical products	13.0	14.1	9.9	1.43
25 Manufacture of rubber and plastic products	6.3	5.6	5.0	1.14
26 Manufacture of other non-metallic mineral products	3.8	4.5	4.8	0.94
27 Manufacture of basic metals	3.4	3.1	3.2	0.98
28 Manufacture of fabricated metal products, except machinery and equipment	5.0	4.2	5.3	0.80
29 Manufacture of machinery and equipment NEC (not elsewhere classified)	11.3	13.5	9.4	1.44
30 Manufacture of office, accounting and computing machinery	0.4	0.0	0.2	0.00
31 Manufacture of electrical machinery and apparatus NEC	4.6	4.8	3.5	1.36
32 Manufacture of radio, television and communication equipment and apparatus	2.1	0.8	1.3	0.64
33 Manufacture of medical, precision and optical instruments, watches and clocks	1.7	1.4	1.3	1.12
34 Manufacture of motor vehicles, trailers and semi-trailers	4.2	4.8	4.4	1.10
35 Manufacture of other transport equipment	1.3	1.4	1.6	0.91
36 Manufacture of furniture; manufacturing NEC	2.1	1.1	3.2	0.35
	100.0	100.0	100.0	

Table 3
Importance of research by academic discipline. Linked firms.
Source: The Survey 2005 and The Survey 2006.

ISIC Rev 3, 2 digits	*N*	Agronomy (%)	Computer Science (%)	Food Science and Technology (%)	Biology (%)	Industrial Design (%)	Civil Engineering (%)	Engineering of Materials and Metallurgy (%)	Mining Engineering (%)	Electrical Engineering (%)	Mechanical Engineering (%)	Chemical Engineering (%)	Physics (%)	Geosciences (%)	Mathematics (%)	Medicine (%)	Veterinary (%)	Chemistry (%)
Percentage of firms indicating the field of research is "moderately" or "very" important for their innovative activities, per sector																		
15 Manufacture of food products and beverages	86	48	17	62	14	21	7	10	0	21	22	34	7	2	3	5	12	26
16 Manufacture of tobacco products	5	80	20	20	20	20	0	20	0	20	0	0	0	0	0	0	0	0
17 Manufacture of textiles	15	20	33	13	13	53	7	13	0	13	13	40	7	0	0	0	13	33
18 Manufacture of wearing apparel; dressing and dyeing of fur	10	10	20	0	0	30	10	30	0	0	10	10	0	0	0	10	0	0
19 Tanning and dressing of leather; luggage, handbags, saddlery, footwear, etc.	8	0	13	0	0	25	0	13	0	13	38	63	13	0	0	0	0	38
20 Manufacture of wood and of products of wood and cork, except furniture	8	50	25	0	0	25	0	38	0	13	13	0	0	0	0	0	0	0
21 Manufacture of paper and paper products	6	0	0	0	0	67	0	17	0	0	0	17	0	0	0	0	0	17
22 Publishing, printing and reproduction of recorded media	4	0	25	0	0	25	0	0	25	25	0	25	0	0	0	0	0	25
23 Manufacture of coke, refined petroleum products and nuclear fuel	2	0	0	0	0	50	0	50	0	50	50	0	50	0	0	0	0	0
24 Manufacture of chemicals and chemical products	50	16	14	16	24	10	0	4	2	16	14	44	10	0	0	24	8	54
25 Manufacture of rubber and plastic products	20	0	15	15	0	10	5	15	0	5	15	20	0	0	0	0	0	5
26 Manufacture of other non-metallic mineral products	16	0	13	0	0	25	31	25	38	25	31	31	0	19	0	0	0	13

27 Manufacture of basic metals	11	0	27	0	0	45	27	55	0	36	27	18	0	0	0	0	0	9
28 Manufacture of fabricated metal products, except machinery and equipment	15	7	27	13	0	20	20	73	0	20	33	27	13	0	0	0	0	0
29 Manufacture of machinery and equipment NEC (not elsewhere classified)	48	21	17	10	0	54	8	48	6	33	48	13	13	2	10	0	0	6
31 Manufacture of electrical machinery and apparatus NEC	17	0	6	0	0	47	12	35	12	47	41	6	0	0	6	0	0	0
32 Manufacture of radio, television and communication equipment and apparatus	3	0	0	0	0	0	0	0	0	67	0	0	0	0	0	0	0	0
33 Manufacture of medical, precision and optical instruments, watches and clocks	5	0	20	20	20	20	20	0	0	20	0	40	20	0	20	20	0	20
34 Manufacture of motor vehicles, trailers and semi-trailers	17	0	18	0	0	35	0	29	0	6	29	6	0	0	0	0	0	6
35 Manufacture of other transport equipment	5	0	60	0	0	80	0	40	0	0	40	0	0	0	0	0	0	0
36 Manufacture of furniture; manufacturing NEC	4	0	50	0	0	25	0	50	0	25	50	25	0	0	0	0	0	25
All sectors	355	20	18	21	8	30	8	24	4	21	25	26	6	2	3	5	5	19

Table 4
Sample characteristics in terms of innovativeness.
Source: The Survey 2005 and The Survey 2006.

	Innovative in products		Innovative in processes		Innovative in products or processes	Innovative in products & processes
	Total	Introducing new products	Total	Introducing new processes		
% of linked	54.0	39.7	55.6	31.3	67.3	42.0
% of control	46.2	27.3	44.1	19.7	59.7	30.7

Table 5
Modes of interaction.
Source: The Survey 2006.

	Classification of modes	Average importance 0.25–1 scale	Moderately or very important ($A > 0.5$) (%)
		A	B
Informal exchange	Traditional	0.58	51
Publications	Traditional	0.56	47
Conferences	Traditional	0.54	46
Hiring graduates	Traditional	0.44	27
Consultancies	Service	0.44	26
Research contracts	Service	0.42	26
Joint R&D	Bi-directional	0.42	25
Licences	Commercial	0.38	16
Networks	Bi-directional	0.37	15
Patents	Commercial	0.37	15
Scientific parks	Bi-directional	0.35	12
Internships	Service	0.34	10
Incubators	Commercial	0.3	5
University owned firms	Commercial	0.27	3
Spin off	Commercial	0.27	2

(e.g. consultancies and contract research). The least frequent modes of interactions are the most commercial ones (e.g. spin off, incubators, patents/licences, etc.), which suggests that entrepreneurial capabilities at PRO are not highly developed. Moreover, activities that involve active participation at both sides of the interaction (e.g. networks, joint R&D and scientific parks) are not very frequent either (see Arza and Vazquez, 2010, for an analysis of the relative effectiveness of different modes of interactions by Argentinean firms.).

Table 6 analyses the mains goals for interaction. The most important goals are related to the use of PRO's infrastructure, either to perform tests or for quality control. These are also the goals more frequently paid for. The goals that follow in importance are related to PRO's human resources, either to get technological advice from researchers or to recruit students. These goals are rarely paid for. Among goals related to firms' capabilities, it is more common that firms contact PRO to contribute rather than to supplement innovative activities.

It is striking the low incidence of firms that pay for the interaction with PRO. This may highlight that linkages are rather informal or at least that they are not formally paid for. For example, if we look at the incidence of payment for the three most important goals, only 55%, 48% and 30%, respectively, declared to have paid for these services. In general, the pattern is that the more important the goal is conceived, the more likely it will be paid for. However, in the above mentioned examples, there are still around 19%, 25% and 52%, respectively, of firms that although considering the goals *very* important, do not pay for the service.

Table 7 shows that 88% of firms consider that the linkages with PRO were successful or expected to be successful in terms of their goals. Although success seems a little bit more frequent for innovative firms, the difference is not significant. In contrast, the bigger the firm, the larger is the probability of success.

Those that considered that collaboration failed (or expected to fail) pointed out that a "mismatch between available knowledge in PRO and the one the firm needed" was the most important reason (among nine) that explained the failure. The second most important was "low sensitivity of PRO to the demands of industry", and the third, "PRO research too oriented to basic science".

Most PRO–industry interactions (69%) lasted less than 5 years (Table 8). Innovative firms seem to have longer-term interaction than non-innovative firms; however, the difference is not significant. On the contrary, there is a significant relation between size and duration: large firms seem to manage to establish longer-term interactions than small firms.

Table 9 presents the main reasons that explain firms' lack of interactions with PRO. The most important reason why firms do not collaborate with PRO is that firms believe they do not need it because their in-house R&D is enough to obtain innovative results. Most control firms consider this reason of moderate importance, at least. However, there is a higher predominance of large firms in this group. The second most important reason is that firms consider that PRO do not have a proper understanding of their line of business, and the third reason is the difficulty in establishing contractual agreements with PRO.

In sum, this section showed that linkages occur predominantly in some sectors, namely chemical industry and production of machinery, mainly in the fields of chemical engineering and industrial design. Linked firms are relatively large and they seem to be more innovative than unlinked firms—although we will verify this properly later in the paper. Firms connect to PRO mostly through traditional channels (e.g. publications, conferences and training) or to demand specific services (e.g. consultancies and contract research). The primary goals for connecting to PRO are related to the use of PRO infrastructure as a service provider for testing, monitoring and quality control. Linkages aiming at supplementing or contributing to firms' innovative activity are less important. Most linkages were considered successful in terms of their goals but they very rarely last longer than 5 years, which may be related to the specificity of main goals pursued by linked firms—mostly connected to the provision of services using PRO infrastructure. Moreover, there is a high incidence of unpaid interactions. Firms that do not connect to PRO argue that they did not need so because their own R&D was enough to innovate.

4. Methodology

Our research question requires comparing the behaviours and perceptions of linked and unlinked firms. However, factors that

Table 6
Goals of interaction.
Source: The Survey 2006.

Goals	Related to	Average importance 0.25–1 scale	Moderately or very important ($A > 0.5$) (%)	Paid interactions for fairly important goals (when $A > 0.25$) (%)
		A	B	C
To perform tests necessary for products/processes	PRO's infrastructure	0.56	46	55
To help in quality control	PRO's infrastructure	0.52	41	48
To get technological/consulting advice from researchers and/or professors in solving production-related problems	PRO's human resources	0.48	34	30
To make earlier contact with excellent university students for future recruiting	PRO's human resources	0.44	27	24
To contract research to contribute to firm's innovative activities	Firms' capabilities	0.42	21	29
Technology transfer	PRO's knowledge resources	0.41	23	31
To use resources available at universities and public labs	PRO's infrastructure	0.41	21	30
To augment firm's limited ability to find and to absorb technological information	Firms' capabilities	0.41	21	17
To get information about engineers or scientists and/or trends in R&D in the field	PRO's knowledge resources	0.40	19	10
To contract research that substitute research that firm does not perform	Firms' capabilities	0.38	14	28

Table 7
Frequency of success of PRO–industry interaction.
Source: The Survey 2006.

	Innovativeness		Size			Total
	Non-innovative	Innovative	Small	Medium	Big	
Successful linkage (%)	58	64	52	60	66	62
Failed linkage (%)	13	9	21	8	9	10
Success expected (%)	26	26	23	30	25	26
Failure expected (%)	3	1	4	2	1	2
Total (%)	100	100	100	100	101	100
Total (*N*)	**115**	**238**	**56**	**97**	**200**	**353**

Table 8
Duration of PRO–industry interaction.
Source: The Survey 2005 and The Survey 2006.

	Innovativeness		Size			Total
	Non-innovative	Innovative	Small	Medium	Big	
Less than 1 year (%)	38	30	47	37	26	33
Less than 2 years (%)	13	18	18	14	16	16
Less than 5 years (%)	20	20	13	19	22	20
Less than 10 years (%)	12	7	2	11	9	9
More than 10 years (%)	18	26	20	19	26	23
Total (%)	100	100	100	100	100	100
Total (*N*)	**112**	**238**	**55**	**97**	**198**	**350**

make behaviours and perceptions different between these groups could also be at the core of the explanation of why some firms interact while others do not. This resembles the type of analysis done in the evaluation literature, when some outcome variables are measured for treated and untreated units. Since the treatment decision is not usually random and the factors that affect

Table 9
Main reasons for not interacting with PRO.
Source: The Survey 2006.

Reasons	Average importance 0.25–1 scale	Moderately or very important ($A > 0.5$) (%)
	A	B
Our firm's R&D is enough to innovate	0.48	53
PRO have no understanding of our line of business	0.43	31
Contractual agreements are difficult	0.43	29
PRO are concerned only with big science	0.40	22
Intellectual property issues	0.38	25
Quality of research is low	0.38	14
Difficulties in dialogue	0.37	13
Lack of trust	0.37	16
Geographic distance	0.34	11

treatment can also affect the outcome variables to be compared, in a seminal work, Rosenbaum and Rubin (1983) proposed a propensity score matching as a method to control for the bias that occurs when comparing outcome variables for treated and untreated data.

In terms of our research goal, we need to compare behaviours and perceptions for firms that share similar characteristics in all relevant factors besides being linked or not to PRO. In other words, the goal is to construct a valid counterfactual group against which we may compare outcomes for the linked group. In what follows we describe the method. Section 4.1 describes the propensity score method and presents the data requirement for an effective calculation. Section 4.2 presents the matching methods used in this paper to construct the counterfactual group.

4.1. The propensity score method

The propensity score method attempts to find a twin among the untreated observations for every single treated observation. Then, the treatment effect is calculated as the average difference

of the specific outcome variable (e.g. innovative expenditures) between treated cases (linked firms) and their untreated twins (unlinked matched firms).

The rationale for this approach is that the bias is reduced when the comparison of outcome variables is done for pairs that are very similar except for the fact that one has been treated and the other has not. In order to make this manageable, an index is calculated (i.e. the propensity score). This index reflects the probability of being treated conditional on relevant characteristics and it is defined as

$$p(X) \equiv \Pr[D = 1|X] = E[D|C] \quad (1)$$

where $p(X)$ is the propensity score, D is a dummy for treatment and X is a multidimensional vector for pre-treatment characteristics.

Rosenbaum and Rubin (1983) showed that if exposure to the treatment is random for all characteristics (X) is also random for the index $p(X)$. In other words, matching based on a single index $p(X)$ (which reflects the probability of treatment) produces as consistent estimates of the treatment effect on the outcome variable as matching done based on all characteristics in the multidimensional vector X.

However, it could be the case that no twin could ever be found for a particular treated observation because there is no case in the untreated group that resembles closely enough the propensity score of such treated observation (i.e. the propensity score of the treated observation is an extreme value). In such a case, those 'rare' treated observations must be left out of the analysis. This is what is called the *common support requirement*. In our dataset this was not necessary as all treated observation lied within the common support region.

Before discussing the different methods to find matching twins it should be noted that the balancing hypothesis must be satisfied. This is to say that the characteristics of units with similar propensity scores are very similar, regardless of whether they are treated or not. In other words, the balancing test proves that the procedure has managed to balance all relevant characteristics in the treated and untreated group, or to put it differently, that both groups resemble closely in all relevant dimensions. The propensity scores that we have calculated passed the balancing test.

4.2. The matching method

Once we have calculated the propensity score we need to construct the untreated group that would work as counterfactual. There are different methods available to select the best possible match.

The most straightforward is the *nearest-neighbour method*, which implies to find for each treated case the untreated case that shows the closest propensity score. Slightly more sophisticate is the *caliper method*, by which the twin is only searched within a range. When there is no untreated case within the range, the treated case is left out of the analysis. In other words, this method is forcing the common support requirement mentioned before. Both methods were performed with replacement, that is, one single untreated case could be used more than once in the counterfactual group if it appears to be the closest untreated firm of more than one treated case.

Two further methods were used in this paper: the kernel and the radius methods. These methods use multiple comparators rather than just the closest (or the closest within a range). The *kernel method* uses information for all non-treated cases to construct each twin. These are weighted according to their proximity in terms of the propensity score using a normal distribution centred in zero (i.e. the highest weight is given to non-treated cases whose difference to the treated case in terms of the propensity score is closest to zero). The *radius method* is similar to the *caliper* mentioned before although it considers all non-treated cases within the radius with equal weight.

5. Determinants of linking

This section investigates the determinants of linking using a Probit model. Therefore, we identify micro and meso drivers for linking to PRO, which fulfils the first research goal (i.e. determinants of firms' interactions with PRO). We will use this estimation to calculate the propensity score which is necessary to fulfil the second research goal (i.e. whether firms that interact behave in innovation and perceive PRO differently than those that do not interact).

A great part of the literature that studies firms' collaboration with PRO has been dedicated to identify firms', industries', and PRO's characteristics that affect the probability of forming linkages. The determinants more often investigated are firms' size (e.g. Fontana et al., 2006; Piergiovanni et al., 1997; Santoro and Chakrabarti, 1999; Segarra-Blasco and Arauzo-Carod, 2008), industry or technology characteristics (e.g. Cohen et al., 2002; Garcia-Aracil and De Lucio, 2008; Leydesdorff et al., 2006; Segarra-Blasco and Arauzo-Carod, 2008), network-related characteristics (e.g. Fontes, 2001; MacPherson, 2002; van Rijnsoever et al., 2008), public policy promotion (e.g. Ballesteros and Rico, 2001; Hayashi, 2003; Klerck, 2005), firms' knowledge bases (e.g. Arundel and Geuna, 2004; Giuliani and Arza, 2009; Santoro and Chakrabarti, 1999; Schartinger et al., 2002), and geographical proximity (e.g. Abramovsky et al., 2007; Arundel and Geuna, 2004; Fritsch and Schwirten, 1999; Vedovello, 1997). Therefore, in our model on the firms' determinants for linking we include proxies for most of these variables, subject to data availability.

Eq. (2) presents a simplified version of our Probit model on the determinants of firms' linkages with PRO. There are three sets of explanatory variables: related to firms' characteristics, network characteristics and the sectoral specificities.

$$linked = \alpha\, firm\_charac + \beta\, net\_charac + \gamma\, sector\_charac + u \quad (2)$$

We must highlight that we make our best to secure the goodness of fit of our participation model (Eq. (2)) trying different specifications. It is known that the quality of the matching is strictly related to the quality of the propensity estimate. Therefore, it is highly important to take good care of the estimation of Eq. (2). The variables included in the estimation were those indicated as important in the received literature, basically related to firm's size, firm's knowledge base, its networking capabilities and also sectoral specificities as mentioned above. In the Probit specification used to estimate the propensity score, we opted to include the proxies for those variables that better fit the model passing the balancing test. This implied, for example, that we included skill per size group in the Probit model to estimate the propensity to link to PRO (Table 10) because such specification showed the better joint significance.

The first set of variables in Eq. (2) contains firm's specific characteristics: size and skills by quintile of size. The second set is about firm's networking behaviour; it includes: a dummy for connection to suppliers and clients, another dummy for connections to other firms in the group, a final dummy for connections to the headquarter and another two variables that account for the firm's own evaluation of the importance of connections to other firms either to exchange information or to do research activities. Finally, the third set of variables is defined at sectoral level (2 digits ISIC) to account for unobservable sector-related factors related to three issues: intensity of investment in innovative activity, productivity and propensity to link to PRO. The specific

Table 10
Probit estimation on the probability of interaction to PRO.
Source: The Survey 2005 and The Survey 2006.

Variable name	Short description	Marginal effects
Size	Deciles based on employment for the full sample	0.026** [0.011]
Skill_size1	Skill in deciles 1 and 2	0.005 [0.387]
Skill_size2	Skill in deciles 3 and 4	−0.882* [0.485]
Skill_size3	Skill in deciles 5 and 6	0.246 [0.220]
Skill_size4	Skill in deciles 7 and 8	−0.112 [0.235]
Skill_size5	Skill in deciles 9 and 10	0.093 [0.258]
Link_vert	Vertical linkage	0.316*** [0.045]
Link_group	Linkage within the group	0.082 [0.058]
Link_hq	Linkage with the headquarters	−0.111* [0.066]
Ch_of_info	Importance of information exchange with other firms	−0.549*** [0.119]
Ch_of_res	Importance of research activities with other firms	0.169 [0.135]
IA_sector	Innovative activities over sales for the sector full sample	0.568 [1.908]
q_sector	Productivity for the sector full sample	0.011 [0.011]
Linked_sector	Quantity of linked firms in the sector	0.003*** [0.001]
Observations		592
Pseudo *R*-squared		0.12
Wald		88.91***

Robust standard errors in brackets.

* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

definition of all variables included in Eq. (2) may be found in the Appendix.

Table 10 shows the results. Size differences persist in our sample. Most sectoral variables, instead, are not significant, except for the one that measures the intensity of linking across sectors. In relation to the network behaviour, the results are interesting. We include indicators of different nature to assess network behaviour.

On the one hand, we include dummy variables that capture whether firms establish connections to other agents during the same period they establish linkages with PRO. For these indicators we find that firms that have connections with other firms in their value chain (*link_vert*) are more likely to be connected to PRO than firms that operate in isolation. This may be related to the existence of network capabilities widely reported in the literature. At the same time, we find that firms that establish linkages with the headquarters (*link_hq*) are less likely to establish linkages with PRO. In other words, foreign firms with connections to global networks are less likely to establish connections to the local public knowledge network, which may suggest that some sorts of global interactions work as substitutes to local networks.

On the other hand, we include two extra variables that capture networking behaviour with other firms regarding the *importance*, according to firms themselves, of two modes of interaction: related to information exchange (*ch_of_info*) and to doing research (*ch_of_res*). We find that the higher the importance allocated by firms to information exchange with other firms, the less likely they will connect to PRO. This is not the case for the importance of interacting with other firms for doing research, which shows a positive sign albeit not significant.

Thus, it seems that while connectivity to private agents in the value chain anticipates connectivity to PRO, this is not the case when such connection is done primarily for information exchange. One may adventure that when information exchange is the primary goal for connectivity, this may be done *either* with PRO *or* with other firms. In other words, when looking primarily for information provision firms' connectivity to PRO may be a substitute for connectivity to other private agents. In contrast, for research activities, the connectivity with other firms or PRO seems to be more complementary.

Finally, our proxy for firm's knowledge bases (*skills*) does not seem to have a clear effect on the probability of linking. According to the literature, firms' knowledge bases should be an important factor that affects the formation of linkages between PRO and firms (Giuliani and Arza, 2009). However, while there are reasons to predict a positive effect, there are also others that justify a negative effect.

On the one hand, firms with more developed knowledge bases may be in an advantageous situation to search and exploit external knowledge, such as the one produced by PRO. This is similar to say that firms with more sophisticate knowledge bases enjoy better absorptive capacity (Cohen and Levinthal, 1990) since knowledge resides in skilled workers (Nelson and Winter, 1982). Moreover, PRO will also tend to prefer the connection with better prepared firms, especially when collaboration implies joint innovative activities.

On the other hand, as we said above, linking to PRO in our sample is very broadly defined and as seen in Table 5 firms do not usually connect to PRO to be involved in research activities themselves but they do so to acquire information or to contract services. This may not be very demanding on their skills. Similarly, the main goal for interacting is to use PRO infrastructure (Table 6) which may not require particular skills either. Moreover, some studies have highlighted that firms' sometimes connects to PRO to substitute areas of research (e.g. Dussauge et al., 2000; Miotti and Sachwald, 2003; Veugelers and Cassiman, 2005) that otherwise they may have done in-house. In such a case, firms with poorer knowledge resources or with knowledge bases narrowly localised, may be found to connect to PRO with higher probability. This may be more likely among small firms, with lower human resources capacity to cover different areas of expertise.

Our results somehow confirm the latter presumption. We included the proportion of skilled workers divided by firms' size, assuming that firms' scale may interfere in the relation between knowledge bases and the probability of linking to PRO. We found that for fairly small firms (those in the third and fourth decile of employment) the more skilled the human resources the less likely firms will be connected to PRO. This may imply that this group connects to PRO in order to overcome their poor knowledge capabilities. None of the other results on skills by size are significant.

6. Differences in perceptions and behaviours between linked and unlinked firms

The most common indicator of interaction used in the literature is cooperation in R&D between firms and PRO. Previous

research usually assesses the effect of interaction on firms' innovative behaviour (e.g. R&D intensity), innovative outcomes (e.g. products and process innovations and patents) and economic performance (e.g. productivity, export intensity, etc.).

Most studies that analyse R&D cooperation find a positive effect on innovative behaviour and performance (e.g. Belderbos et al., 2004; Fritsch and Franke, 2004; Kaufmann and Todtling, 2001; Loof and Brostrom, 2008; Monjon and Waelbroeck, 2003; Todtling et al., 2009). Instead, some mixed results can be found when interactions are measured more broadly and not just by R&D cooperation (e.g. Arvanitis et al., 2008; Arza and Vazquez, 2010). Moreover, some research argues that PRO research feeds firms' innovative activities even in the absence of direct interactions (e.g. Beise and Stahl, 1999; Mansfield, 1991, 1998; Nelson, 1986).

Regarding the effects of PRO–industry interactions on firms' economic performance results are mixed (e.g. positive results were found by George et al., 2002, while no significant difference in firms' performance was found by Motohashi, 2005) but they tend to be dependent on the goals of the interactions since many cooperative agreements target pre-competitive research (Benfratello and Sembenelli, 2002).

As we have explained in Section 4, this section compares firms' behaviour and perceptions in terms of a group of outcome variables. We use four different matching methods but the results do not vary widely among them, which enhances the robustness of our research design.

Having defined different counterfactual groups according to different matching methods, we pursue to measure the effect of linking on different outcome variables. In particular, we are interested in knowing whether firms that connect to PRO are different in terms of (a) innovative behaviour, (b) success in achieving product or process innovation, (c) attitude towards patenting their innovative outcomes, (d) access to sources of finance for innovation and (e) conceptions about the importance of outcomes and roles pursued by PRO.

We calculate the average treatment effect on the treated group (ATT), or in other words the average difference in the outcome variables between the treated group (i.e. firms linked to PRO) and the counterfactual group (i.e. twin firms – according to different matching methods – that are not linked to PRO). Table 11 lists all variables and the definition for each type of outcome (a)–(e). It is worth noting that this information is available for the same year for which the firm declared to have been linked to the PRO (i.e. 2005), therefore we are evaluating the contemporaneous effect.

Tables 12a–12e list the results on the impact of linking on the different group of variables listed in Table 11. The first columns in these tables list the relevant variables. The second columns present the matching methods. The third columns present the average values for all non-treated observation (all firms with no linkages). The fourth columns correct these values calculating the average only for the unlinked twins of linked firms (i.e. based on each specific matching method of the propensity scores). The fifth columns present the average value only for linked firms. Final the sixth columns calculate the ATT, which is the difference between the previous two columns. Finally, to assess the confidence of the estimated ATT we bootstrap the standard error of the estimate building up a confidence interval. We add to each ATT *** when it was significant at 1%, ** at 5%, and * at 10% based on the bootstrapping strategy.

Table 12a) presents the results for variables related to innovation inputs. Linked firms invest around 2.8% of their sales in innovative activities, which comprises 1.5% of sales in machinery and 0.9% of sales in in-house innovative activities. The remaining 0.5% of sales includes hardware and intangible technologies such as licences, consultancy, external R&D and software. When compared against unlinked firms, linked firms invest significantly more in total innovative activities, machinery and in-house innovative activities. The difference in all items suggests that investment intensity is around 25% higher for linked firms.

Table 12b) presents the impact of linking on innovative outcome. Since the outcome variables and linking activities refer to the same year (2005), we cannot interpret the results as impacts for being linked to PRO, which may only become noticeable with some lag. We must interpret this result as difference predisposition towards innovation between linked and twin unlinked firms. Around 53% of linked firms have innovated in products and around 55% in processes. Among unlinked firms, 46% innovate in products and 44% innovate in process. Once relevant characteristics are matched, the difference shortens. Among twin unlinked firms, there are around 51% that innovate in products and around 45% that introduce process. Therefore, the ATT is only significant for process innovation calculated by most matching methods. In contrast, the ATT for product innovation is never significant.

Interestingly, Table 12c) shows that linked firms are more likely to obtain patents than unlinked firms. While 5% of linked firms obtained at least one patent in 2005, among twin unlinked firms,

Table 11
Outcome variables to assess the ATT on linked firms.
Source: The Survey 2005 and The Survey 2006.

Variable group	Variable name	Type of data	Variable definition
(a) Innovative behaviour	IA_sales	Ratio	Total expenditures in innovative activities over sales
	ima_sales	Ratio	Expenditures in machinery for innovation over sales
	inhouse_sales	Ratio	Expenditures in R&D and Design and Engineering over sales
(b) Innovative outcome	inn_prod	Dummy	Whether the firm obtains innovations in products (new or significantly improved)
	inn_proc	Dummy	Whether the firm obtains innovations in processes (new or significantly improved)
(c) Appropriability behaviour	patent	Dummy	Whether the firm obtains patents
(d) Sources of financing innovation	fin_int	Percentage	Percentage of total innovative activities financed by own resources, including resources from other firms within the group and headquarters
	fin_pro	Percentage	Percentage of total innovative activities financed by PRO
(e) Perception of PRO	import_pro_	1–4 re-scale to 0.25–1	Four categorical variables that accounted for the importance of PRO outcomes as perceived by firms: (1) Publications (import_pro_pub), (2) Prototypes (import_pro_prot), (3) Techniques and tools (import_pro_tech), (4) Laboratories/ Metrology (import_pro_lab)
	role_pro_	1–4 re-scale to 0.25–1	Four categorical variables that accounted for the roles PRO should pursue as perceived by firms: (1) Education (role_pro_edu), (2) Research (role_pro_res), (3) Social (role_pro_soc), (4) Entrepreneurial (role_pro_entr)

Table 12a
ATT of linking to PRO on firms' innovative behaviour (12a,12b,12c,12d).
Source: The Survey 2005 and The Survey 2006.

Variables	Weight methods	Means			ATT
		All unlinked firms before matching	Unlinked firms after matching (control group)	Linked firms	Difference of means of linked—unlinked firms
IA_sales	Nearest neighbour	0.0224	0.0164	0.0280	0.0116***
	Kernel (normal)	0.0224	0.0192	0.0280	0.0088**
	Radius	0.0224	0.0182	0.0285	0.0104**
	Caliper	0.0224	0.0169	0.0285	0.0117***
ima_sales	Nearest neighbour	0.0136	0.0086	0.0152	0.0065**
	Kernel (normal)	0.0136	0.0102	0.0152	0.0050*
	Radius	0.0136	0.0093	0.0157	0.0064**
	Caliper	0.0136	0.0088	0.0157	0.0069**
inhouse_sales	Nearest neighbour	0.0051	0.0050	0.0089	0.0039*
	Kernel (normal)	0.0051	0.0055	0.0089	0.0035*
	Radius	0.0051	0.0054	0.0088	0.0034*
	Caliper	0.0051	0.0052	0.0088	0.0036**

* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

Table 12b
ATT of linking to PRO on firms' innovative outcomes.
Source: The Survey 2005 and The Survey 2006.

Variables	Weight methods	Means			ATT
		All unlinked firms before matching	Unlinked firms after matching (control group)	Linked firms	Difference of means of linked - unlinked firms
inn_prod	Nearest neighbour	0.4599	0.5256	0.5369	0.0114
	Kernel (normal)	0.4599	0.4921	0.5369	0.0448
	Radius	0.4599	0.5094	0.5315	0.0221
	Caliper	0.4599	0.5075	0.5315	0.024
inn_proc	Nearest neighbour	0.4388	0.4773	0.5540	0.0767
	Kernel (normal)	0.4388	0.4418	0.5540	0.1122***
	Radius	0.4388	0.4337	0.5556	0.1218**
	Caliper	0.4388	0.4595	0.5556	0.0961*

* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

Table 12c
ATT of linking to PRO on firms' appropriability behaviour.
Source: The Survey 2005 and The Survey 2006.

Variable	Weight methods	Means			ATT
		All unlinked firms before matching	Unlinked firms after matching (control group)	Linked firms	Difference of means of linked - unlinked firms
Patent	Nearest neighbour	0.0169	0.0057	0.0511	0.0455***
	Kernel (normal)	0.0169	0.0090	0.0511	0.0422***
	Radius	0.0169	0.0090	0.0450	0.0361***
	Caliper	0.0169	0.0060	0.0450	0.0390***

*** Significant at 1%.

Table 12d
ATT of linking to PRO on firms' uses of sources of finance for innovation.
Source: The Survey 2005 and The Survey 2006.

Variables	Weight methods	Means			ATT
		All unlinked firms before matching	Unlinked firms after matching (control group)	Linked firms	Difference of means of linked—unlinked firms
fin_int	Nearest neighbour	0.8416	0.8548	0.7848	−0.0700*
	Kernel (normal)	0.8416	0.8448	0.7848	−0.0601**
	Radius	0.8416	0.8589	0.7825	−0.0764**
	Caliper	0.8416	0.8685	0.7825	−0.0860***
fin_pro	Nearest Neighbour	0.0111	0.0000	0.0185	0.0185***
	Kernel (normal)	0.0111	0.0089	0.0185	0.0095
	Radius	0.0111	0.0088	0.0184	0.0096
	Caliper	0.0111	0.0000	0.0184	0.0184***

* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

less than 1% obtained patents. For the same reasons expressed above, this cannot be interpreted as linked firms being more innovative; in fact, patenting would take even longer time than being successful in innovative products or processes. Therefore, we interpret these results as linked firms being more prone to using appropriability tools such as patents. It must be noted that by comparing twins we compare firms of similar size and other relevant micro characteristics. Thus, if it were true that linked firms are those particularly interested in using tools to guard the intellectual property rights (Arundel, 2001), issues of concerns about the risks of privatisation of public knowledge could be raised.

Table 12d) shows the firms linked to PRO systematically use less internal sources of finance of their innovative expenditures than firms that do not connect. In any case, internal sources of finance are clearly very important for both groups: for linked firms they represent 78% of their innovative expenditures while for twin unlinked firms they represent 85%. On the contrary, linked firms use a larger proportion of funds provided by PRO. The difference is

Table 12e
ATT of linked and unlinked perceptions about PRO.
Source: The Survey 2006.

Variables	Weight methods	Means			ATT
		All unlinked firms before matching	Unlinked firms after matching (control group)	Linked firms	Difference of means of linked—unlinked firms
import_pro_pub	Nearest neighbour	0.5770	0.5675	0.6200	0.0526
	Kernel (normal)	0.5770	0.5803	0.6200	0.0398
	Radius	0.5770	0.5780	0.6194	0.0413
	Caliper	0.5770	0.5586	0.6194	0.0608
import_pro_prot	Nearest neighbour	0.4789	0.4737	0.5014	0.0277
	Kernel (normal)	0.4789	0.4822	0.5014	0.0193
	Radius	0.4789	0.4855	0.5000	0.0145
	Caliper	0.4789	0.4805	0.5000	0.0195
import_pro_tech	Nearest neighbour	0.5612	0.5412	0.6555	0.1143***
	Kernel (normal)	0.5612	0.5571	0.6555	0.0984***
	Radius	0.5612	0.5503	0.6539	0.1036***
	Caliper	0.5612	0.5420	0.6539	0.1119***
import_pro_lab	Nearest neighbour	0.5253	0.4943	0.6342	0.1399***
	Kernel (normal)	0.5253	0.5306	0.6342	0.1036***
	Radius	0.5253	0.5233	0.6321	0.1088***
	Caliper	0.5253	0.4947	0.6321	0.1374***
role_pro_edu	Nearest neighbour	0.7691	0.7138	0.7521	0.0384
	Kernel (normal)	0.7691	0.7512	0.7521	0.001
	Radius	0.7691	0.7591	0.7553	−0.0038
	Caliper	0.7691	0.7222	0.7553	0.033
role_pro_res	Nearest neighbour	0.6568	0.6634	0.7031	0.0398
	Kernel (normal)	0.6568	0.6632	0.7031	0.0399
	Radius	0.6568	0.6736	0.7035	0.0299
	Caliper	0.6568	0.6577	0.7035	0.0458
role_pro_soc	Nearest neighbour	0.6176	0.6065	0.5774	−0.0291
	Kernel (normal)	0.6176	0.6237	0.5774	−0.0463
	Radius	0.6176	0.6244	0.5841	−0.0403
	Caliper	0.6176	0.6029	0.5841	−0.0188
role_pro_entr	Nearest neighbour	0.5742	0.5582	0.527	−0.0313
	Kernel (normal)	0.5742	0.5821	0.527	−0.0551
	Radius	0.5742	0.5865	0.5338	−0.0551
	Caliper	0.5742	0.5563	0.5338	−0.0225

significant in two of the four matching methods, thus results are not robust. However, these sources represent a tiny proportion of funds use for innovative expenditures (a bit less than 2% in average for linked firms and 1% in the case of unlinked firms).

Finally, Table 12e) presents different indicators on the perception that linked and unlinked firms have about PRO. The first four indicators are about the importance that firms allocate to different outputs produced by PRO. The last four are about the roles that firms perceive PRO should have.

It is not unexpected that linked firms value systematically more research outputs that need geographically close interactions to be exploited (e.g. such as instruments or laboratories). In average, linked firms answered that these outputs were of some importance, while in average unlinked firms considered them unimportant. On the contrary, it is interesting that both linked and unlinked firms consider publications as important and prototypes as unimportant. Thus, linking to PRO seems to have no effect on the importance that firms allocate to outputs that can be enjoyed at arm-length.

Finally, the roles that PRO should have according to firms' perception do not vary between linked and unlinked firms. All firms consider that the most important role is education followed by research. Although, linked firms seem to value research more than unlinked firms, the difference is not significant. In contrast, firms consider that social and entrepreneurial roles of PRO are much less important. Unlinked firms seem to give more value to the social role than linked firms, but again this difference is not significant.

7. Conclusions

This paper departs from the presumption that drivers and characteristics of PRO–industry linkages in developing countries differ from their parallel in the developed world, which justifies the need of PRO–industry interaction in developing countries. The research studies the case of PRO–industry linkages in Argentina, a developing country where public–private partnership have been promoted since the late 1990s. The paper has two goals: firstly, we analyse firms' drivers for linking to PRO. Secondly, we examine whether innovative behaviour and firms' perceptions about PRO outputs and roles in the NSI are different for linked and unlinked firms.

The first goal is achieved by estimating a Probit model on the propensity to link to PRO. For the second goal, we use propensity score matching techniques. These techniques enable us to control for all relevant characteristics that may be influencing simultaneously the propensity to be linked and the outcome variables of behaviours and perceptions.

The data used come from the Argentinean Innovation Surveys of 2005 and 2006. In the Survey 2006 an especial section was added to the general questionnaire to evaluate in detail firms' interactions with PRO that occurred in 2005 and also to a group of unlinked firms that resembled the characteristics of the linked group in terms of size and sectoral affiliation. Based on that group we construct the counterfactual to assess the effect of linking using propensity score matching techniques.

We first present fairly comprehensive descriptive statistics on most variables included in the survey since this data has not been presented before. Besides describing the characteristics of the sample, that section examines the main motivations and channels of interactions. It is showed that firms primarily collaborate to take advantage of PRO infrastructure and human resources and they do so, to substitute the innovative activities they do not perform. Strikingly, there is a low incidence of payment for interacting. Nevertheless, most interactions are considered successful in terms of achieving the expected goals. The main channels are traditional channels such as information exchange, publications, conferences and training graduates followed by channels that implied the provision of services.

In relation to our first goal (drivers of PRO–industry linkages) our conclusions are as follows:

i. There is no clear effect of firms' knowledge bases on the probability to interact. For small firms the effect is negative (they seem to be overcoming their weak capabilities by interacting with PRO) and the effect is not significant for larger firms.
ii. Regarding networking activities,
   a) We find that firms that establish linkages with clients and suppliers are more likely to establish linkages with PRO as well, showing that networking capabilities have a role to play.
   b) Firms that connect to headquarters, however, are less likely to establish linkages with PRO, which suggested that there is a sort of substitution effect for foreign firms between linking to global and to national partners (or at least to PRO).
   c) There is a substitution effect between PRO and 'the market' for information exchange. Firms that interact to other firms for information exchange interact less with PRO. This does not occur for interactions motivated by research activities, for which there seems to be a weak form of complementation between the market and PRO.

In relation to our second goal (differences in behaviours and perception between linked and unlinked firms), we conclude that:

iii. Linked firms invest more intensively in both, in-house innovative activities and technology embodied in machinery.
iv. Link firms seem to be more successful in process innovation, although the robustness of this result is lower than the previous one. This should not be interpreted as differences in innovative performance because, due to data restrictions, we are bound to assess the contemporaneous effect of linking on innovative outcome. We interpret this finding as different *predisposition* towards innovation.
v. Linked firms are more prone to patenting. Given the time lags between new ideas that may be triggered by the interaction with PRO and the opportunity to obtain patents, we interpret this finding as a differential strategy towards intellectual property protection by those firms that interact with PRO.
vi. Linked firms use a lower proportion of internal resources and a higher proportion of PRO resources to finance their innovative activities.
vii. Linked firms tend to value more than unlinked firms PRO research outputs that require geographically close collaboration (i.e. new tools, laboratories and equipment) but no significant difference is found for the value of research outputs that could be available at arm length (e.g. publications). Moreover, for both linked and unlinked firms, the primarily roles of PRO are teaching and research rather than entrepreneurial or social roles.

These empirical conclusions derive the following thoughts that may become useful for future policy design for the promotion of PRO–industry linkages in developing countries.

Firstly, attention should be placed to the *knowledge value* implied in linkages with PRO. The rationale for the promotion of linkages is that they favour knowledge creation and diffusion within the NSI. However, firms' knowledge capabilities are not drivers for linking in our case of study. In general, firms connect to PRO regardless of their skills and small firms with low level of skills are more likely to connect than small and skilful firms. Moreover, the main goals for linking are the provision of services and the use of PRO infrastructure. This means that PRO would not be necessarily learning when interacting with firms and it raises concerns about the extent to which some PRO (e.g. universities) could be misusing their knowledge resources when interacting with firms.

We believe there is potential for knowledge creation and diffusion in PRO–industry interactions, but we also believe that not all types of interactions are equally valuable. For example, we find that when firms interact seeking for information exchange (rather than pursuing research activities) they substitute interacting with PRO for interacting with other firms. In such a case, when firms could satisfy their knowledge demands in the market it would be better to encourage market interactions rather than to interfere in PRO principal activities of teaching and research, unless PRO main function were to support weak firms—which is rarely the case of universities but may be the case of some public institutes. It is worth noting that we find that firms consider PRO research outputs useful for their innovative activities even in the absence of direct interactions (e.g. unlinked firms value PRO publications as much as linked firms). Thus, linking is not necessarily a pre-requisite for PRO to become useful for firms' innovative activities. It may well be a good idea to design a division of labour among (or even within) PRO so that some (predominantly public institutes) may become specialised in providing basic support for productive requirements posed by

Table A1

Variable group	Variable name	Type of data	Variable definition
Firms' network behaviour	linked	Dummy	Whether the firm interacts with PRO
	link_vert	Dummy	Whether the firm is linked to suppliers or clients
	link_group	Dummy	Whether the firm is linked to other firms within the group
	link_hq	Dummy	Whether the firm is linked to headquarters
	ch_of_info	1 – 4 re-scaled to 0.25 – 1	Average importance, according to the firm itself, of interactions related to information exchange (i.e. publications, conferences, informal information exchange, and exhibitions)
	ch_of_res	1 – 4 re-scaled to 0.25 – 1	Average importance, according to the firm itself, of interactions related to doing research (i.e. contracted research, joined research, products, licences)
	goals_	1 – 4 re-scaled to 0.25 – 1	Six categorical variables: one for six different goals for linking to PRO: (1) to improve absorptive capabilities (goal_abs), (2) to contribute to innovative activities (goal_contr), (3) to substitute innovative activities (goal_suppl), (4) to take advantage of PRO's human resources (i.e. to get advices from researchers and to hire students at an early stage) (goal_hr), (5) to take advantage of PRO's infrastructure and machinery resources (i.e. quality control, monitoring and testing and other resources) (goal_cap), (6) to take advantage of PRO's knowledge resources (i.e. technology transfer and other information from the scientific field) (goal_k)
	pay_	Dummies	Six dummy variables to account for whether the firm pays or not to pursue each of above-mentioned goals
Firms' characteristic	size	Categorical 0–10	Deciles based on employment defined for the full ENIT 2005 (1675 firms). Deciles' upper limits (employees): 1=16, 2=27, 3=40, 4=60, 5=85, 6=116, 7=156, 8=229, 9=411, 10=all bigger than 411
	skills	Ratio	Professional employees over total employment
Firms' innovative behaviour	IA_sales	Ratio	Total expenditures in innovative activities over sales
	imaq_sales	Ratio	Expenditures in machinery for innovation over sales
	inhouse_sales	Ratio	Expenditures in R&D and Design and Engineering over sales
	fin_int	Percentage	Percentage of total innovative activities financed by own resources, including resources from other firms within the group and headquarters
	fin_pro	Percentage	Percentage of total innovative activities financed by PRO
	patent	Dummy	Whether the firm obtained patents
	inn_prod	Dummy	Whether the firm obtained innovations in products (new or significantly improved)
	inn_proc	Dummy	Whether the firm obtained innovations in processes (new or significantly improved)
Sector characteristics	IA_sector	Ratio	Total employment over sales for the whole sample of ENIT 2005 for 8 groups of sectors (see INDEC, 2008)
	q_sector	Ratio	Total employment over sales for the whole sample of ENIT 2005 per sector (2 digits ISIC)
	linked_sector	Ratio	Sum of firms that were connected to PRO per sector (2 digits ISIC)

firms while the rest (especially universities) could focus on their main functions related to teaching and research and they would link following these main imperatives.

Secondly, we provide some evidence that suggests that linked firms are contemporaneously more innovative than unlinked firms. However, we also find that firms usually interact to substitute for the innovative activities they do not perform and they do not always pay for the interaction. We believe it is important to develop policy tools that avoid crowding out effects in innovation. It is important that if firms linked to PRO they did so to complement rather than to substitute their own innovative efforts. In this sense, it may be a good idea to attach some target in terms of investing in in-house innovation as a requirement for firms to interact with PRO.

Finally, special attention must be placed on issues of intellectual property rights. In this paper we find the firms that are linked to PRO seem to be more prone to protecting their intellectual property using patents. In the Argentinean context, as it is the case in most developing countries especially in Latin America, there is no systematic protection of publicly created knowledge, private firms may find little resistance when intending to patenting outputs triggered by their interactions with PRO. The effect of this on the strategic diffusion of publicly created knowledge must be analysed further. The challenge for science and technology policy is to avoid what Nelson, 2004 called the tragedy of the scientific commons, which may occur if agents maximising their own benefits endanger the wide diffusion of (publicly created) knowledge.

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Appendix. Variables' definition

See Table A1.

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Valeria Arza is researcher in economics of innovation at the Argentinean National Research Council (CONICET) and at CENIT-Argentina (www.fund-cenit.org.ar) and Lecturer in the University of Buenos Aires (UBA). She completed a postdoctoral study on University–Industry interactions at Matisse at the *Centre d'Economie de la Sorbonne*. She holds a Ph.D. from SPRU, University of Sussex (Thesis: *The Impact of Business Confidence and Macroeconomic Uncertainty on Firms' Investment Behaviour in Argentina During the 1990s)*, and a M.Sc. from the London School of Economics. She has done research on several topics related to the determinants on firms' innovative behaviour in developing countries. More in particular, she has published papers in Journals and book chapters on the role of the environment on firms' investment decisions and the relevance of public/private and global partnerships for technology diffusion.

Andrés López is researcher in economics of innovation at the Argentinean National Research Council (CONICET) and is Director of CENIT-Argentina (www.fund-cenit.org.ar). He is full Professor and Head of the Department of Economics of the University of Buenos Aires (UBA). He holds a Ph.D. from UBA (Thesis: Economic Development and National System of Innovation (NSI): The Argentinean Case 1860–2001). He has done research about foreign direct investment (FDI), innovation and productivity in developing countries. He coordinates a network of institutions studying several issues on regional integration processes (www.redmercosur.net). He has published books about the Argentinean NSI, MERCOSUR, globalisation and FDI. He also published dozens of articles in Journals and book chapters in topics related to Innovation Studies.