Channels, benefits and risks of public–private interactions for knowledge transfer: conceptual framework inspired by Latin America

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There are both benefits and risks involved in interactions between public research organisations (PROs) and industry. This paper proposes a conceptual framework that associates firms' and PROs' motivations, channels of interaction and benefits. It suggests that each channel triggers predominant types of benefits and claims that policy-making to support PRO–industry (PRO-I) interactions should be selective. Policy design must take into consideration the skill-related characteristics of the actors, and the characteristics of the interaction channels in order to achieve the best possible balance between the benefits and risks of PRO-I interactions. The geographical focus of the discussion is Latin America.

INTERACTIONS THAT OCCUR BETWEEN the private sector and PROs have the potential to create and diffuse knowledge, but imply some risks related mainly to the privatisation of public research outputs and also to the diversion of the research agenda away from socially more useful purposes. Most of the literature on PRO-I interactions designed to inform policy either supports or disapproves the promotion of more intense linkages. In fact, there have been very few attempts in this literature to distinguish the particularities of interactions using different channels.

This paper discusses the channels of PRO-I interactions and the associated benefits and risks in developing countries, with a focus on Latin America. We make two main claims. First, the channel of PRO-I interaction used by firms and researchers is defined by the specific combination of goals that motivates the interaction. Secondly, since the benefits of interactions are generally in line with the initial motivation, certain channels of interactions are more likely to result in certain types of benefits for each of the actors (i.e. firm and PRO). Similarly, the risks associated with PRO-I interactions vary depending on the interaction channel.

We believe that this paper is relevant to science and technology policy (STP) because it discusses the pros and cons of certain channels of interactions being promoted rather than others in order to achieve particular benefits and avoid some of the risks. Jointly assessing the benefits and risks is essential if PRO-I interactions are to work to upgrade the overall national system of innovation (NSI).

The paper is organised into five sections. The second section highlights the specificities of PRO-I interactions in Latin America. The third section advances the discussion on the motivations and benefits of PRO-I interaction and proposes a conceptual framework which relates the motivations, interaction channels and benefits. The fourth section extends the conceptual framework to consider the potential social risks of PRO-I interaction. Finally, specific hypotheses are derived, which are then tested in the

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empirical contributions in this special issue of *Science and Public Policy*.[1]

PRO-I interactions in developing countries, with focus on Latin America

Most of the theoretical and empirical research on PRO-I interactions focuses on developed economies. However, the requirements for developing countries to upgrade their NSIs are different from those in developed countries (Mazzoleni and Nelson, 2007), as are their PRO-I interactions.

First, the socio-economic needs are different. Unlike the usual reality in developed countries, large fractions of the population in developing countries live in poverty. Moreover, the income distribution is highly unequal, and education and health systems are deficient, which perpetuates social inequality. Furthermore, the level of pollution, largely the result of outdated production technologies, is distressing.

All these features create specific demands on PROs, which are often not comparable to the demands of economic activity in developed countries. As Mazzoleni and Nelson (2007) claim, the key to catching up is research that is useful for the individual country. Thus, research needs to be oriented to the social needs of users. However, in a context where many technology users are poor, which means that their needs may not be converted into effective market demand, the demand exerted by private firms on PROs may not agree with the needs of the majority (Ravjee, 2002).

Secondly, both PROs and firms in developing countries have specific and distinctive characteristics compared to their counterparts in developed countries. A strong scientific base is a prerequisite for catching up, as historical experience shows (Mazzoleni, 2008). For example, Liefner and Schiller (2008) claim that among academic institutions in developing countries there are no synergies in terms of the three missions of teaching, research and outreach (including PRO-I interactions). According to Liefner and Schiller, one of the characteristics of these institutions is the fragmentation of their various functions.

Although there is a long tradition of good quality scientific research in many Latin American PROs,[2]

there is also evidence of functional fragmentation between research, teaching and outreach activities. Moreover, STP has not been consistent over time and, consequently, the developmental role assigned to PROs has not been continuous.[3] In this context, the promotion of PRO–firm interactions, although emphasised more since the 1990s, has not been part of an integrated STP plan, but the result of isolated policy actions, usually seeking economic benefits for the under-funded PROs.[4]

Similarly, the average technological dynamism of firms in developing countries cannot be compared to that of similar firms in developed countries. PRO-I interactions can be effective only if there is proactive demand for knowledge in the industry (Mazzoleni and Nelson, 2007). Firms' 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 actors in the local system (Giuliani and Arza, 2009).

The literature on PRO-I interactions in Latin America often claims that an important limitation for the wide diffusion of interactions is lack of industry demand for sophisticated technological knowledge,[5] or, at least, poor demand for domestic sources of knowledge: foreign firms demand technology from their headquarters, and many local firms prefer to import technologies (Velho, 2003). Similarly, some authors note that the productive structure in Latin America is not knowledge intensive and, therefore, is deriving fewer benefits from PROs,[6] which, in turn, means that PROs have fewer opportunities for applications.

In sum, the small literature that specifically studies PRO-I interactions in developing countries in general, and in Latin America in particular, points to the idiosyncrasies of firms and PROs and the motivations for PRO-I interactions. None can be assimilated to those in developed countries. This justifies the need for more specific research on PRO-I interactions and their benefits in developing countries. This special issue tries to fill this gap using the case of Latin America.[7]

Conceptual framework of relationships between motivations, channels of interactions and their benefits

Actors' motivations for linking

In order to schematise the analysis, we classify the various motivations for interacting into two main groups for each actor: economic and intellectual for PROs, and passive and proactive for firms. This classification constitutes the main pillar of our conceptual framework.

It should be noted that, although a two-by-two classification of the motivations for interacting necessarily involves simplification of the reality, we believe it is justified in the Latin American case. In

fact, a dichotomy between firms' passive and proactive strategies is common in the literature on Latin American firms. Many argue that a general lack of confidence in the sustainability of any state of affairs, due to high macro-economic uncertainty, explains firms' defensive (passive) strategies,[8] which need to be counterbalanced by policies designed to reward proactive schemes. Similarly, in the case of researchers, it is often argued that Latin American PROs (and especially universities) have traditionally been disconnected from (and usually opposed to) the private sector. However, it has been claimed that the increased tendency for researchers to interact with firms is due to budget pressures[9] (rather than intellectual motivations).

Motivations for PROs In the case of researchers working in PROs, interacting with firms may respond to the PRO's institutional imperatives or may result from researchers' individual motivations. In either case, we can identify two 'ideal types' of motivations.

On the one hand, there may be institutional imperatives to diversify funding resources for infrastructure and staff support which drive interaction with industry. Researchers may also be seeking to complement their personal incomes (i.e. individual motivation).[10] We refer to these motivations as the PRO's economic strategies.

On the other hand, PRO-I interaction may be triggered by the primary goals of the PRO to enhance the quality of research and teaching by learning in the context of application or by learning about production technologies which may be useful for further research. This strategy could be part of an institutional imperative or respond to the researcher's personal ambitions to produce original and high-quality research outputs.[11] In other words, PRO-I interaction may fulfil the PRO's (and researchers) intellectual strategies by, for example, suggesting new avenues for exploration, monitoring the latest technological developments, tackling challenging problems etc.[12]

Motivations for firms In order to cope with acceleration in technological change, innovative firms need to gain access to the knowledge produced by PROs because, in many productive activities, scientific knowledge weighs increasingly more in technological upgrading. Thus, for many firms, the main motivations to interact with PROs are the need to 'identify and exploit external and applied technological opportunities to a full extent' (Bonaccorsi and Piccaluga, 1994: 232). In other words, the strategy may be designed to gain access to scientific knowledge to enable the firm to become a real innovator (i.e. to push the technological frontier). Of course, such a strategy demands a high level of knowledge commitment and proactive behaviour on the part of the firm, not only to absorb the externally produced knowledge, but also to contribute to the creation of technological knowledge suitable for

productive activities. We refer to this firm motivation for PRO-I interaction as a proactive strategy. In this case, PRO-I interaction is a key component of the firm's innovation strategy and interaction will be aimed mostly at obtaining and creating updated, and usually tacit, knowledge to solve technological bottlenecks (Brostrom *et al.*, 2009).

Other motivations to interact with PROs include reducing some development costs (e.g. testing and monitoring) or operating costs by substituting internal innovation or production activities with external sources (e.g. gaining access to PRO facilities at subsidised rates) (Bonaccorsi and Piccaluga, 1994). In this case, the knowledge received will be highly codified and mature, and it will not demand very sophisticated knowledge resources from the firm, although there is a minimum threshold for knowledge from external sources to be absorbed. Thus, PRO-I interaction would not necessarily be a component of an innovation strategy. Firms would be more interested in solving concrete and fairly simple, short-term production problems than thinking in the long-term. We refer to this type of firm motivation to interact with PRO as a passive strategy.

Benefits of PRO-I interactions

The literature is generous in identifying the different types of benefits that firms and PROs can expect from their interactions. We organise them into four groups in line with the motivations for linking discussed in the previous section: *intellectual* or *economic* benefits, for PROs; and contributing to *innovation* strategies or solving short-term *production* problems, for firms.

Intellectual benefits for PROs Research may be inspired by industry applications and knowledge exchange with industry (Meyer-Krahmer and Schmoch, 1998), which provide new insights for the research agenda (Fritsch and Schwirten, 1999; Lee, 2000). This applies particularly to research fields located in the 'Pasteur quadrant' (Stokes, 1997), which advance through simultaneous performance of basic and applied research (e.g. all types of engineering, biotechnology, metallurgy, computer science etc.). Both the quality and quantity of the knowledge produced by PROs can improve from their responding

Firms and PROs can expect various benefits from interacting. There can be intellectual or economic benefits, for PROs. For firms benefits can contribute to innovation strategies or solve short-term production problems

to the opportunities opened up (or problems faced) by innovative firms.

Some scholars have attempted to assess whether PROs become more productive in terms of knowledge creation (usually measured by publications) from interacting with firms. Most show that collaboration is positively associated with research productivity.[13]

Economic benefits for PROs   In line with the motivations, the literature confirms that obtaining extra funds is one important benefit of PRO-I interaction.[14] There is also evidence that by commercialising their research, PROs learn to identify the most valuable research from the pool of their inventions (Owen-Smith and Powell, 2003) and, therefore, become better at raising private funds (i.e. a self-reinforcing mechanism is in place).

Benefits related to firms' long-term innovation strategies   Some problems faced by industry demand a combination of technologies that no single firm could develop on its own, but which can be solved by exploiting the knowledge stock in PROs (Patel and Pavitt, 1995). Thus, PRO-I interactions contribute to firms' innovation strategies, leading to innovative outcomes. Moreover, the technological upgrading of linked firms may be conducive to broader economic and social development due to knowledge spill-overs.[15]

Benefits related to short-term production activities by firms   PROs widen the capacity of industry to solve real production problems. First, universities provide training for graduates who then take up

employment and contribute to production and innovative activities in the private sector (Rosenberg and Nelson, 1994). This occurs even if the PROs do not strategically orient their teaching programmes to topics that industry considers relevant. Furthermore, PROs develop new laboratory instruments and analytic methodologies that constitute fundamental inputs for industry (Rosenberg, 1992). Finally, PROs produce knowledge related to the economic and social context in which firms produce and trade, which could influence the ultimate success of their production decisions (Fritsch and Schwirten, 1999).

Conceptual framework

The analytical framework proposed in this section combines the motivations for firms and researchers discussed in the section of this paper on the actors' motivations for linking, highlighting specific channels of interactions that best serve each combination of motivations. Moreover, since it is benefits that are associated with the initial motivations for interacting, we show that each channel of interaction creates a predominant, specific combination of benefits.

Figure 1 depicts the motivations of firms and PROs. The vertical axis represents PROs strategies and the horizontal axis represents firms' strategies. These strategies are not dichotomous and should be read as a continuum between two extremes: at the extreme for PROs are intellectual strategies (i.e. learning in the context of application) and economic strategies (i.e. accessing new sources of funding); at the extreme ends for firms are proactive and passive strategies.[16] We classify channels based on these
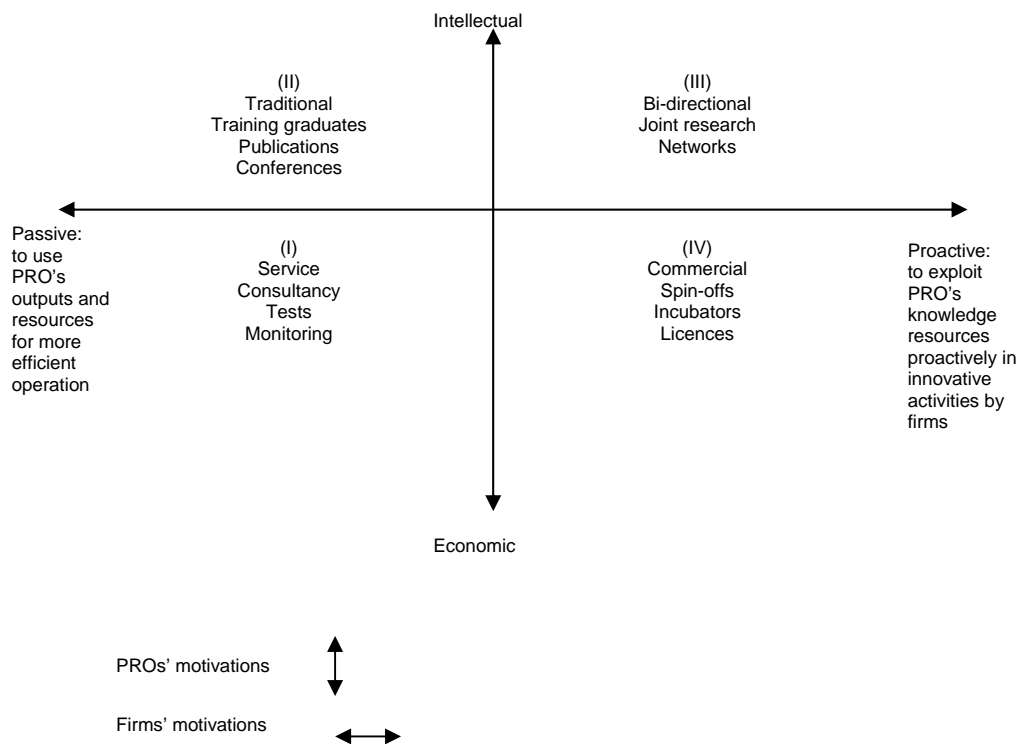

Figure 1. Motivations and channels of interaction

four extremes, depicted in the four quadrants in Figure 1.

- Quadrant (I) contains interactions motivated by economic strategies by PROs and passive strategies by firms. The result is interactions that could be associated with the provision of scientific and technological services in exchange for money, where knowledge flows mainly from PROs to firms (e.g. consultancy, use of equipment for quality control, testing and monitoring etc.). These are usually short-tem interactions. Although there may be some degree of personal interaction, much of the knowledge transmitted is mature and can be transferred without intense face-to-face collaboration.

- Quadrant (II) is defined by the intellectual strategies of the PRO and the passive strategies of the firms. We refer to it as the traditional channel because it resembles the traditional ways that firms benefit from actities by PROs (e.g. hiring graduates, conferences, publications etc.). Knowledge flows mainly from PROs to firms, but the knowledge content is defined by the traditional functions of the academic/research institutions. Personal interaction between the individuals from the different institutions is not required in this case.

- Quadrant (III) includes interactions that originate from the intellectual strategies of the PROs and proactive strategies by the firms. In this case the knowledge flow is bi-directional and the potential for joint learning is high. This quadrant includes joint research and development projects, participation in networks, scientific–technological parks etc. Generally, personal interaction is required throughout the period of the interaction agreement (usually more than one year).

- Quadrant (IV) is defined by the economic strategies of PROs and proactive strategies by firms. This is the commercial channel of interactions, where the main motivations for PROs are the keenness to commercialise their scientific results. Emblematic examples of this channel are spin-off companies and incubators. Also included are

technology licensing and firms' exclusive rights on patented products or processes, whose invention is based on PRO-I interactions. Personal interaction is usually required in the first stages of the relationship when the parties have to agree on the type of knowledge that is being commercialised. Also, it is argued in the literature that this channel is more effective when systematic and direct relations between institutional members are established.[17]

The originality of this framework lies in the use of the motivations of the PROs and firms as the relevant dimensions for classifying PRO-I interactions. This helps us to relate the channels of interactions to the benefits triggered by the interactions. The literature highlights the existence of a variety of forms of PRO-I interactions (Bekkers and Freitas, 2008; D'Este and Patel, 2007). Channels have been classified according to the degree of formality in the organisational agreements,[18] the degree of articulation and personal communication between the actors,[19] and the relative potential for conveying novelty.[20] It is also argued that the intensity of use of different forms of interaction is sector, field and/or technology specific.[21] The literature on channels of PRO-I interactions mainly analyses what determines the use of different channels[22] or identifies the variety and relative frequency of the use of different channels by specific actors.[23] It tends to overlook the relation between channels of interactions and the benefits they potentially trigger.[24]

In classifying channels according to the original motivation we are one step away from relating channels to benefits. Table 1 presents hypotheses on the relations between channels and benefits. We claim that different channels prioritise some types of benefits over others. This does not mean that each channel triggers only one/some types of benefits: rather it means that, *ceteris paribus*, each channel predominantly contributes to certain types of benefits for the actors, more explicitly, those that correspond to the initial motivations for interacting.

Thus, it would be expected that traditional and bi-directional channels should yield intellectual benefits for PROs, and service and commercial channels

Table 1. Predominant benefits expected from channels of PRO-I interactions

Channels	Benefits			
	PROs		Firms	
	Intellectual	Economic	Short-term (production)	Long-term (innovation)
Service		X	X	
Traditional	X		X	
Bi-directional	X			X
Commercial		X		X

would yield economic benefits for PROs. For firms, bi-directional and commercial channels may be the most effective way to convey novelty and, therefore, to facilitate technological upgrading. These channels involve a higher level of articulation than other channels, promoting the transmission of tacit knowledge (Perkmann and Walsh, 2007). Tacit knowledge usually conveys more novelty than explicit/codified knowledge because the latter is less costly and, therefore, diffuses widely. Thus, PRO-I interactions using these channels are expected to be more conducive to innovation outcomes for firms.

In contrast, since the traditional and the service channels generally involve the diffusion of codified and mature knowledge, it is less likely that interactions using these channels will contribute to path-breaking solutions. Yet, they may provide insights for marginal improvements of processes or products.

Finally, the relationship between channels and benefits is expected to be mediated by firms' innovative capabilities and researchers' knowledge skills.

The literature is very clear about the positive role of a firm's capabilities to increase the effectiveness of any interaction.[25] Firms need to have achieved a minimum threshold of internal capabilities to be able to absorb and integrate external knowledge (e.g. knowledge obtained through the traditional and service channels). If firms are to be proactive in the process of knowledge creation (i.e. if they use the bi-directional and commercial channels), the threshold is likely to be higher.

For PROs, the effect of knowledge skills on benefits may depend on the channel of interaction. As pointed out above, researchers who interact with PROs have frequently been found to be the best qualified or most productive in terms of publications. Second-tier PROs or researchers with lower quality skills may also interact with industry. However, these interactions are usually different in nature and are aimed mainly at solving simple and immediate problems (Fukugawa, 2005; Mansfield and Lee, 1996). In this case, interactions may target knowledge diffusion rather than knowledge creation. In fact, researchers with less sophisticated knowledge skills probably have few opportunities and little interest in, or ability to, undertake 'blue skies' research. They may prefer to be involved in less ambitious research, more oriented towards problem-solving for industry (D'Este and Patel, 2007), through consultancies or other services.

In sum, knowledge skills are important factors mediating the effectiveness of the PRO-I interactions through the bi-directional (Fukugawa, 2005) and commercial channels (Lockett *et al.*, 2005; Wright *et al.*, 2008). In those cases the contribution made by the knowledge is highly relevant to convey the novelty that may solve technological bottlenecks. However, benefits can still be obtained by lower-skilled researchers who choose to use the service or traditional channels.

Extending the conceptual framework to achieve more relevant policy recommendations: social risks of PRO-I interactions

Since the 1990s, the governments of many countries have attempted to improve the relations between PROs and firms (Dasgupta and David, 1994; Etzkowitz *et al.*, 2005; Nelson, 2004; Slaughter and Leslie, 1997) in the expectation that strong and widely diffused PRO-I interactions would strengthen innovation in the NSI. In the case of the Latin American countries, the impetus to support those relations was accompanied by the imperative to increase and diversify sources of funding for PROs, which were facing serious cuts to their budgets (Arocena and Sutz, 2005).

Our conceptual framework demonstrates that PRO-I interactions can give rise to different types of benefits, depending mainly on the channels used. The claim that the benefits to be gained through the interactions are not necessarily homogeneous suggests the need for more targeted support for specific channels of interactions according to the policy objectives. We would claim, therefore, that the relevance of our conceptual framework, if validated by empirical data, is that it is rooted in the contribution to a better and more informed policy design that optimises the promotion of PRO-I interactions.

However, our conceptual framework only explores the private benefits reaped by PROs and firms, assuming somehow that these benefits exceed their private costs associated with interactions, which explains the initial decisions to interact. However, some recent studies highlight a series of potential costs (i.e. risks) involved in PRO-I interactions that may affect the creation and diffusion of knowledge in the NSI as a whole (i.e. social risks). Since policy recommendations cannot be derived without analysing the social risks of the interactions, we need to extend our conceptual framework to explore the extent to which they may be associated with the use of specific channels.

This section discusses the literature that identifies social risks related to the intensification of PRO-I interactions. These risks do not necessarily directly affect the actors involved in interactions, but may induce adverse effects on the quality and effectiveness of knowledge production and diffusion by the NSI as a whole. They must therefore be considered in any policy analysis. We classify them into four groups and end this section of this paper with a discussion of whether or not each channel of interaction implies specific types and levels of risks.

First, there is the question of the quality of the research that is triggered by PRO-I interactions. Two risks emerge: the risk of unethical behaviour due to conflicts of interest and the risk of attention being diverted away from research that is socially more useful.

- The integrity and quality of teaching and research comes under threat when interactions create

conflicts of interest between these activities, and the needs of the funders. It has been shown that, especially in the area of clinical research, interactions may induce researchers to hide research outputs that conflict with the interests of private funders.[26]

- PRO-I interactions involve the risk of diverting attention away from certain research lines towards those that serve the needs of those with market power (Parkinson and Langley, 2009). This implies that research carried out in PROs could be re-oriented in directions that benefit linked firms (and perhaps also some consumers and other interconnected firms), but which do not necessarily meet the needs of the majority of the population.[27] This is a particular risk in the context of high inequalities in income, such as occur in Latin America.

Secondly, there may be opportunity costs when the time devoted to interaction implies less time for teaching and research, or when the research abandoned due to a changed research agenda resulting from PRO-I interaction, would have been of higher social value than the research actually pursued. Most of the literature on opportunity costs in research discusses whether, by interacting, researchers at PROs reduce the time devoted to fundamental (basic) research.[28] However, opportunity costs are more often an issue of concern in relation to training students.[29] It is claimed that the quality of training is reduced because students are pushed to be involved in the PRO-I interactions of their research groups. This implies that they become less autonomous, have less opportunity to explore their own research paths, and are in danger of becoming too specialised too soon: all of which will undermine the quality and independence of research in future generations. This concern is particularly relevant when interactions are motivated by financial constraints in PRO, which, again, often applies to Latin American PROs.

Thirdly, there is the risk of privatisation of public research outputs. In their interactions with industry PROs produce useful research outputs to continue research downstream. Nelson (2004) argues that fundamental knowledge from science, even if it is in fields of research with semi-immediate application, must remain open to public use. There is evidence that firms demand exclusive rights in the form of patents, or secrecy when they interact with PROs

(e.g. Godfrey, 2005). For example, Blumenthal *et al.* (1996) claim that industrial partners are more likely to impose secrecy on universities than other partners would. Power asymmetries, which amplify the risks of privatisation, are frequently present in developing countries, especially in relation to intellectual property rights claims if large and/or multinational corporations are involved in the interactions.

Fourthly, there is the issue of PRO accountability. When research agendas are decided autonomously by PROs, there is a risk of loss of accountability to funders (both government and private sector), which may derive in socially futile public research activities. Moreover, in PRO-I interactions, researchers may appropriate scientific results and start their own businesses, or they may act as brokers diffusing information to partner firms' competitors, creating conflicts with the private funders. Nevertheless, beyond misbehaviour, there are also real uncertainties in the process of knowledge creation which promote conflicts in the distribution of responsibilities and duties (Bonaccorsi and Piccaluga, 1994).

Speculations about the relationship between channels and risks We can revise the four channels of interactions through critical reflection on the intensity of different risks (summarised in Table 2).

- Service channel: First, since this channel involves knowledge diffusion rather than knowledge creation, and under the assumption that researchers' knowledge skills are strong, PRO that use this channel intensively may be subject to high opportunity costs (i.e. there may be socially more useful things in which to invest the researchers' time). Secondly, since most of the knowledge transferred through this channel is mature, there is less risk of publicly produced knowledge becoming privatised. There is also a lower risk that conflicts of interest will emerge, although this can occur, especially if private funds obtained through this channel represent a large proportion of the PRO budget.
- Traditional channel: This channel does not necessarily require personal interactions with industry and it involves research activities which usually follow researchers/PRO own agenda. Thus, although this channel does not imply any of the first

Table 2. Expected intensity of risks for NSI as a whole, using different channels

Channels	Risks			
	Weak quality (conflicts of interest)	Opportunity costs	Privatisation of public research	Lack of accountability of PRO activities
Service	Medium	High	Medium	Low
Traditional	Low	Low	Low	High
Bi-directional	Medium	Low	High	Medium
Commercial	High	Medium	High	Low

three risks described above, there is a high risk of weak accountability of PRO research.

- Bi-directional channel: The knowledge flows in both directions via this channel, and knowledge outputs are supposed to be created based on the contributions of all actors. In a context of power asymmetry, it constitutes a high risk of a privatisation of public research. However, opportunity costs would be expected to be low since researchers follow their intellectual motivations. Given that communication between the actors is frequent and permanent, this would seem to present only a medium risk of poor accountability on the part of the PRO, and of conflicts of interest.

- Commercial channel: This is the channel most often identified in the literature as risky (especially in relation to start-ups and spin-offs).[30] It clearly involves high risks of conflicts of interest, unethical behaviour and privatisation of publicly created knowledge. Since interactions through this channel usually require little personal interactions, mainly at the start of the relationship, opportunity costs are unlikely to be high, but this situation could change if researchers' time is used to support newly born firms.

Conclusion

There are benefits and risks involved in PRO-I interactions. The better they are balanced, the more effective will be the interaction in terms of upgrading the NSI. This paper proposes a conceptual framework that associates actors' motivations for interacting, with channels of interaction. The main hypotheses derived from the framework associate channels with benefits. They can be summarised as follows:

- H1: PRO-I interactions through the *service* channel produce predominantly economic benefits for PROs and contribute to short-term production activities by firms.
- H2: PRO-I interactions through the *traditional* channel produce predominantly intellectual benefits for PROs and contribute to short-term production activities by firms.
- H3: PRO-I interactions through the *bi-directional* channel produce predominantly intellectual benefits for PROs and contribute to long-term innovation strategies by firms.
- H4: PRO-I interactions through the *commercial* channel produce predominantly economic benefits for PROs and contribute to long-term innovation strategies by firms.

These hypotheses are tested in the empirical papers in this special issue of *Science and Public Policy*, using a methodological approach presented in the Appendix to this paper.

We also discussed how knowledge skills and innovative capabilities can act as mediating factors in the relation between channels and benefits. We would suggest that the better the innovative capabilities of firms, the greater the effectiveness of all channels. Regarding researchers' knowledge skills, in our view, they are required for more effective intellectual benefits, especially for the bi-directional channel, but also to reap the economic benefits from the commercial channel.

The final section in the main part of this paper proposes an extended version of the conceptual framework, which explores the extent to which PRO-I interactions could create social risks for the NSI as a whole. This discussion is particularly relevant for policy-makers. Although we speculate about the relations between channels and type and intensity of risks and argue that the commercial channel is the one which creates more intense social risks, further empirical research is needed to derive specific hypotheses, methodologies and empirical validation of the relation between channels and risks.

We now highlight some policy challenges related to harnessing the potential of PRO-I interactions while not absorbing all the risk. First, PRO-I interactions should be supported and regulated selectively. We argue that different channels of interactions bring about specific benefits and risks and claim that these relations are mediated by the specific skills of the actors. Thus, policy-makers should analyse the initial conditions of the actors involved in the interaction, assess the types of benefits to target and the risks to be avoided, and select policy tools to support specific channels of interaction under different conditions.

Secondly, it is worth considering a division of labour in relation to PRO interaction activities to reduce the opportunity costs of the interaction, especially in terms of services. Instead of universities or top research institutes, specially designed public support institutions could be given the responsibility of diffusing mature knowledge through the service channel to all types of firms, including those with weak innovative capabilities. These new institutes could be responsible for diffusing traditional PRO research outputs, promoting internships for students, managing personnel exchanges etc.

Thirdly, since traditional PRO-I interactions are led by market demand, which is not necessarily in line with the needs of the majority of the population, reward mechanisms should be created to promote research aimed at solving social problems (health, housing, environmental) with weak commercial potential.

Finally, there is an urgent need to limit the risk of privatisation of knowledge, and to avoid the 'tragedy of the scientific commons' (Nelson, 2004) that could occur if actors in trying to maximise their own benefits, endanger the wider diffusion of (publicly created) knowledge. This risk arises mainly in relation to the commercial and the bi-directional channels and is particularly relevant in developing countries where large firms have better access than many PROs to intellectual property rights mechanisms.

Appendix: Proposed methodology for empirical validation of the conceptual framework

In order to identify the determinants of the benefits we estimate two sets of equations: one for researchers and one for firms.

Models

Researchers

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

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

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

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

Firms

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

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

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

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

The conceptual framework suggests that different channels of interactions (Ch_i) have the potential to trigger different kinds of benefits, both for researchers (intellectual benefit (IB_i) and economic benefit (EB_i) and for firms (benefit related to production activities (PB_i) and to innovation activities (InB_i) (see Equations (1b), (1d), (2b) and (2d), respectively). Moreover, there are other researcher and firm features (R_i and F_i, respectively) that may affect their benefits, which we include as control variables in the equations. These control variables are informed by the literature.

The benefits, modelled by Equations (1b), (1d), (2b) and (2d), can only be measured for the researchers and firms that actually interact. These researchers and firms may enjoy special characteristics (which promote the interaction in the first place). To deal with potential selection bias we suggest the use of the Heckman two-step method. For the selection part of each Heckman model (Equations (1a), (1c), (2a) and (2c)), the dependent variable (d_V_i) is a dummy variable that equals one when the firm or researcher is connected. The vectors of the independent variables in these equations are the features of researchers (RV_i) and firms (FV_i) that affect their probability of linking, and are also informed by the literature.

Since the selection part of the Heckman estimates the inverse Mills ratio which corrects for selection bias, we need first to identify the best possible model for selection. Different probit model specifications should be contrasted by assessing the goodness of fit of the models (e.g. using the Bayesian information criterion).

All the country studies in this special issue are based on surveys of researchers and firms. In the cases of Mexico and Argentina, both linked and unlinked researchers and firms are surveyed; in the case of Brazil only linked actors are included. Thus, it is not possible to estimate Heckman models in the Brazilian case. Costa Rica is a separate case with complete data on firms, but only linked researchers were surveyed. The authors of the papers in this special issue previously agreed on similar proxies for the key variables, such as the benefits and channels of PRO-I interactions. This allows the results to be compared, which is done in the final paper in this special issue.

Notes

1. This paper is part of the project 'Interactions between Universities and Firms: searching for Paths to support the changing role of Universities in the South (Africa, Asia and Latin America)' financed by IDRC (Canada). This special issue of *Science and Public Policy* discusses empirical findings for the four Latin American countries covered by this project. All the country contributions in this special issue were motivated by the conceptual discussion in the present paper and use the methodological approach in the Appendix to this paper.
2. E.g., three Argentinian scientists working in Argentinian PROs won Nobel Prizes for Science and a Mexican graduate from a public Mexican university won a Nobel Prize for Chemistry based on research conducted at Massachusetts Institute of Technology, USA.
3. See Dutrénit *et al.* (2010), López (2007) and Velho (2005). Nevertheless, PRO research has been and is key to successful experience in some sectors in Latin America. Gutiérrez (1993), and León and Losada (2002) stressed the importance of PRO research for technological upgrading in Argentinian agriculture. Suzigan and Albuquerque (2009) studied the importance of university research for the development of the aircraft, steel and agricultural industries in Brazil.
4. See Arocena and Sutz (2001, 2005), Bernasconi (2005) and Llomovatte *et al.* (2006).
5. See Dagnino and Velho (1998), Moori-Koenig and Yoguel (1998), Sorondo (2004) and Vega-Jurado *et al.* (2007).
6. See Arocena and Sutz (2005) and Casas *et al.* (2000).
7. See the country study papers in this special issue. Other colleagues use similar empirical sources to analyse PRO-I interactions; i.e. Kruss (2009) for African studies and the special issue of the *Seoul Journal of Economics*, (2009) Vol. 22, No. 4, for Asian studies.
8. See Arza (2005), Cimoli and Katz (2003) and Katz (2004).
9. See Arocena and Sutz (2005), Bernasconi (2005) and Vega-Jurado *et al.* (2007).
10. See Azagra-Caro *et al.* (2006), Dasgupta and David (1994), Etzkowitz *et al.* (2005), Lopez-Martinez *et al.* (1994), Nelson (2004), Perkmann and Walsh (2008) and Slaughter and Leslie (1997).
11. See Lee (2000) and Meyer-Krahmer and Schmoch (1998).
12. See Lopez-Martinez *et al.* (1994) and Perkmann and

Walsh (2008).

13. See Abramo *et al.* (2009) Gulbrandsen and Smeby (2005) and Ranga *et al.* (2003).
14. See Geuna (2001), Lee (2000), Mendoza (2007), Meyer-Krahmer and Schmoch (1998) and Stephan and Everhart (1998).
15. See Etzkowitz and Klofsten (2005) and Etzkowitz and Leydesdorff (2000).
16. This figure was inspired in part by Kruss (2005), who organises firm and PRO imperatives for interaction in a four-by-four matrix.
17. See Dahlstrand (1999).
18. See Bonaccorsi and Piccaluga (1994), Eun (2009), Romero (2007), Schartinger *et al.* (2002) and Vedovello (1997, 1998).
19. See Fritsch and Schwirten (1999), Perkmann and Walsh (2007) and Santoro and Saparito (2003).
20. See Romero (2007) and Wright *et al.* (2008).
21. See Bekkers and Freitas (2008) Cohen *et al.* (2002), Meyer-Krahmer and Schmoch (1998) and Schartinger *et al.* (2002).
22. See Bekkers and Freitas (2008), Fukugawa (2005), Schartinger *et al.* (2002) and Vedovello (1997; 1998).
23. See Bekkers and Freitas (2008), Cockburn and Henderson (1998), Cohen *et al.* (2002) and D'Este and Patel (2007). In developing countries, in particular, consultancy is usually considered to be the most common form of PRO-I interaction. See Ojewale *et al.* (2001), Arocena and Sutz (2005), Kruss (2006) and Vega-Jurado *et al.* (2007). probably due to lack of demand from industry and financial pressures that lead PROs to search for new sources of funding.
24. There are some exceptions such as studies aimed at assessing the relative effectiveness of channels; e.g. Wright *et al.* (2008), Adams *et al.* (2003) and Arvanitis *et al.* (2008), although no systematic pattern of types of channels driving specific types of benefits has been proposed.
25. See Bonaccorsi and Piccaluga (1994), Hanel and St-Pierre (2006), Laursen and Salter (2004) and Vedovello (1998).
26. See Blumenthal *et al.* (2006), Campbell and Blumenthal (1999) and Parkinson and Langley (2009).
27. See Florida (1999), Godfrey (2005), Lee (1996) and Mollis and Marginson (2002).
28. See Mansfield (1991, 1998).
29. See Blumenthal (1996), Campbell and Slaughter (1999) and Slaughter *et al.* (2002).
30. See Florida (1999) and Lee (1996).

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