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Developing National Systems of Innovation

University–Industry Interactions in the Global South

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This book is dedicated to:
Daniel Chudnovsky (1944–2007)
Jo Lorentzen (1962–2011)
Dani Nabudere (1932–2011)

Developing National Systems of Innovation

University–Industry Interactions in the Global South

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Preface

Richard R. Nelson

Economic development in countries behind the technological frontier requires innovation both by firms, and by farms, hospitals, and other organizations that provide goods and services. This is not innovation in the sense of introducing something new to the world economy, but of introducing something new to the particular context. In general, in economies that are significantly behind the frontier and that are aiming to catch up, the new practices put in place by firms tend to be modelled on practices that have been employed for some time by firms at the frontier. However, empirical research shows clearly that innovation of this kind has many of the attributes of innovation at the frontier. A large share of these efforts fails. Success generally requires a considerable amount of learning by the firms by doing and using before they acquire the needed capabilities.

This view of the process through which developing economies acquire increased capabilities to produce goods and services is relatively new among economists who study the process. Traditionally, economists have focused on the investments needed. They saw the problem of mastering new ways of doing things as mostly involving "technology transfer", a term that played down the difficult learning processes involved.

In the early writings of development economists on the need for firm learning, the focus was on what the firms themselves needed to do. More recently, there has been growing recognition that firms are part of a community of organizations and institutions whose interactions affect the direction and efficacy of learning. The concept of an "innovation system," which for some time has been employed by scholars of innovation in advanced industrial countries, is now more often used to denote and characterize the complex collection of actors and interactions that are involved in innovation in countries behind the frontiers and striving to catch up.

The research projects in this book focus on a particular part of the workings of innovation systems: the interactions between universities and public laboratories and firms, and how these interactions affect the efficacy of the efforts of firms to acquire new capabilities. In recent years, the relationships between universities and firms, and how these relationships

influence the innovation process, have been extensively studied in high-income countries. The studies reported in this book are among the first to be directed to what is going on in developing countries.

Scholars of economic development, who have employed the innovation systems concept in their study of how developing countries catch up, have been particularly interested in the differences in these structures in developing countries and countries at the frontier. There are two central questions for most of the scholars who have contributed to this book. What is similar and what is different about the relationships between how universities and public laboratories interact with firms in developing as contrasted with advanced industrial economies? How do these differences reflect and support the differences witnessed in on-going innovations? This book is the first large-scale report on these matters, and their implications for policy in developing countries.

Acknowledgements

Introduction

Glenda Kruss, Keun Lee, Wilson Suzigan, and Eduardo Albuquerque

In 2006, the International Development Research Centre (IDRC) of Canada opened a competition on "searching for paths to support the changing role of universities in the South." This competition provided an opportunity for collaboration between research teams from 12 different countries from three continents. The objective was to fill the gap in knowledge about interactions between firms, universities, and research institutes at the periphery.

Universities, research institutes, and firms are key parts of a National System of Innovation (NSI). The interactions between these key components of the NSI are starting points for a dynamic interpretation of the importance, role, and nature of science and technology. The comparative study published by Nelson (1993) is a product of previous work by Christopher Freeman, Bengt-Åke Lundvall, and Richard Nelson (see Dosi et al. 1988, Part V). Nelson and Rosenberg (1993) summarized the concept of an NSI and set the framework of the comparative study. They stressed that the "intertwining of science and technology" (p. 5) was a complex feedback process that resulted in mutual positive feedback between science and technology – "science as leader and follower" (p. 6). Nelson and Rosenberg (1993, pp. 9–13) also present "the major institutional actors," which are "firms and industrial research laboratories" and "other institutional actors" – universities and public laboratories. Those lessons shaped our initial views: investigations of interactions between firms, universities, and public laboratories were now seen as investigations of NSIs – zooming in on specific but important components.

Interactions between universities, research institutes, and firms have been deeply investigated within and outside the NSI framework. Three path-breaking papers that looked at these interactions in the United States are Klevorick et al. (1995), Narin et al. (1997), and Cohen et al. (2002). Before 2005, the focus had been on developed countries.

The IDRC-sponsored tri-continent research was an opportunity to broaden the perspectives of investigations on interactions between firms,

universities, and public research institutes – our 12 countries provide enough diversity and variety to include the "South" in the agenda of this important subject.

TWELVE COUNTRIES: DIFFERENT POSITIONS AND TRAJECTORIES

To show where our 12 countries are located in the international arena and how they are moving within it, we chose statistics that are closest to our research subject: patents and scientific papers (Moed et al. 2004). In general, patents are a proxy for technological production, mainly a task of firms, and scientific papers are a proxy for scientific production, one of the functions of universities and public research institutes. Firms do produce scientific papers and universities patents, but those are not their main roles. Statistics on patents and scientific papers are correlated with the wealth of nations – gross domestic product (GDP) per capita in particular (Dosi et al. 1994). The simple juxtaposition of these statistics may provide hints about interaction between science and technology.

Statistics on patents and scientific papers are easily available, and it is possible to build intertemporal comparisons between different countries. Figure I.1 summarizes where our countries are and how they are moving. Based on previous research (Ribeiro et al. 2006), this figure illustrates two important concepts: "regimes of interaction" and "moving thresholds."

Regimes of interaction is a concept derived from an empirical investigation based on United States Patent and Trademark Office (USPTO) patents and scientific papers indexed by the Institute for Scientific Information (ISI). When all countries of the world are placed on one graph, with their science and technology production per million inhabitants, they cluster in three groups. Those clusters offer an initial reference for the correlation between science and technology: in the first cluster, countries with low technology production also have a low scientific production. At the other extreme, countries in the third cluster have both a high technology production and a high scientific production. If we add GDP per capita to this graph, the lowest GDPs per capita are in the first cluster and the highest are in the third. After the three groups of countries are defined, we can draw two lines: boundaries between the first and second groups and between the second and third groups. Each of those clusters corresponds to one regime of interaction. The limits between them are thresholds. Those thresholds must be overcome as countries evolve from one regime of interaction toward the next.

The second concept is related to those thresholds. When we compare the distribution of the three regimes of interaction over time, it is clear that their thresholds move. As scientific and technological production grows, especially in the leading countries (regime of interaction III), the thresholds move up. This means that, as time goes by, the scientific and technological challenges to the countries at the periphery (regimes of interaction I and II) also increase.

Figure I.1 summarizes information from our 12 countries. The horizontal axis is scientific production (A* – ISI-indexed papers per million inhabitants), and the vertical axis is technological production (P* – USPTO
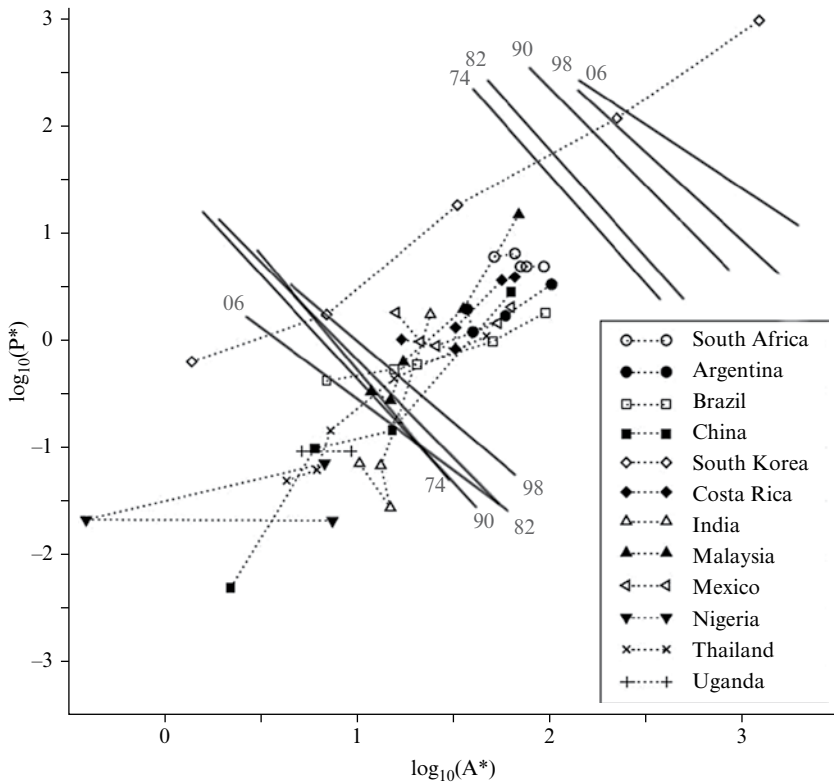
Note: A*: ISI-indexed scientific articles per million inhabitants; P*: USPTO patents per million inhabitants (Ribeiro et al. 2009).

Figure I.1 *Distribution of the 12 countries in the RoKS project by the three regimes of interaction and the moving thresholds between those "regimes" (1974, 1982, 1990, 1998, and 2006)*

patents per million inhabitants). We have data for 1974, 1982, 1990, 1998, and 2006.

Figure I.1 also shows the moving thresholds: the lines in the upper-right part of the figure represent the thresholds between regime of interaction III (in the upper-right part beyond those lines) and regime of interaction II (in the middle of the graph). The dynamics of those thresholds are seen in the systematic upward movement of those thresholds from 1974 to 2006. Figure I.1 also shows the thresholds between regimes of interaction I and II (this is the lower-left part of the graph), which have more erratic movements.[1]

The trajectories of the 12 countries show the diversity and richness of this set of countries (Figure I.1).[2] In 2006, these countries were distributed over the three different regimes of interaction and over time they showed different trajectories.

Figure I.1 shows the distribution of our 12 countries throughout the three "regimes of interaction." In 2006, the 12 countries were distributed through all three regimes: Uganda and Nigeria in regime of interaction I; all four Latin American countries, South Africa, India, Malaysia, Thailand, and China, in regime of interaction II; and South Korea in regime of interaction III. Ribeiro et al. (2006) showed that there is a high correlation between the position in the science-and-technology space (Figure I.1) and GDP per capita – this is the z-axis of a tri-dimensional graph presented by Ribeiro et al. (2006). Therefore, our 12 countries are very representative of different levels of development.

Figure I.1 also displays differences among the trajectories of our 12 countries. First, there is the South Korean trajectory. South Korea was in regime of interaction I in 1974, overcame the threshold between regimes of interaction I and II in 1982, and overcame the threshold between regimes of interaction II and III in 1998 to join the group of developed countries. This is the trajectory of a successful catch up – countries may leave the periphery, overcome underdevelopment, and join the centre of the capitalist economy. This trajectory shows that the peripheral condition is surmountable. The process of overcoming underdevelopment features growth in techno-logical and scientific production, or maturation of NSIs. Improvements in the interaction between science and technology, or between universi-ties, research institutes, and firms must improve over time. According to Keun Lee, "the dynamic evolution of university–industry relations [links]

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[1] The clustering techniques and the method for defining the thresholds between these groups
    are presented by Ribeiro et al. (2006).
[2] Exceptions regarding the years presented in these trajectories are China (data for 1982,
    1990, 1998, and 2006), Nigeria (data for 1990, 1998, and 2006), and Uganda (data for 1998
    and 2006).

underscores the need to see UIL in an evolving process depending on the stage of economic development of a country" (Lee 2009, p. 6).

Second, there is the Chinese trajectory. In 1982, China was in regime of interaction I, but by 2006 China had jumped to regime of interaction II – in a position well ahead of other countries that were earlier in that "regime."

Third, there is a Latin American trajectory. Mexico, Costa Rica, Argentina, and Brazil have been in regime of interaction II since 1982, and they still are there. If we take Brazil as a representative Latin American country, it has improved its scientific and technological production – there is a correlation between both improvements. However, those improvements have only preserved its position relative to the moving thresholds to the regime of interaction III. Similar to other countries in regime of interaction II, Brazil is running in the science and technology (S&T) international arena to stay in the same place relative to the moving threshold – this is a Red Queen Effect.[3] South Africa has been part of regime of interaction II since 1974, and also appears to be under the curse of this "Red Queen Effect."

Figure I.1 and its interpretation suggest that those three regimes of interaction may differ in nature, in the direction of flows, and in the intensity of positive feedback between science and technology. The RoKS project was a terrific opportunity to look closely at these channels and flows across our 12 countries.

ONE COMMON QUESTION, DIFFERENT APPROACHES

In 2007, this research began with a common question for all research projects: How and why do relationships between universities and public laboratories and firms differ across countries and regions at different stages of development, and across sectors? What did our research teams have in common when we started our tri-continent research? We did not have a general theoretical framework covering the interactions between firms, universities, and research institutes, but we did share several ideas.

First, there was a common perception about the importance of these interactions to understand the NSIs in developing economies. The use of the concept of NSIs stressed that our research was not about interactions

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[3] The Red Queen Effect was a metaphor used by Van Valen (1973): regardless of how well a species adapts to its current environment, it must keep evolving to keep up with its competitors and enemies who are also evolving. Thus, the Red Queen Effect: do nothing and fall behind, or run hard to stay where you are.

between universities and firms per se, but about a set of institutions and relationships among them embedded in a broader framework – the NSI. The NSI has a deep (and causal) relationship with development; therefore, the formation of an NSI was recognized as a precondition for overcoming underdevelopment.

Second, these perceptions came from different academic routes – development economics; studies of industrial sectors; investigations of characteristics of NSIs in the periphery; geography of innovation; investigations of the catch-up process; economics of innovation; and investigations of universities and their functions in different societies. Therefore, our tri-continent research teams were not a homogeneous group.

Third, we shared a common discomfort with the lack of studies about interactions between firms, universities, and research institutes in the South, to use a term from the IDRC competition.

Fourth, we were influenced by the strong academic and intellectual incentives created by the Catch Up Project led by Richard Nelson.

Fifth, there was a common feeling that this subject could be investigated in our countries by adapting and improving existing surveys (e.g., the Yale Survey and the Carnegie Mellon Survey), and by inventing new questionnaires that would fit our realities while retaining some comparability with the United States and other developed countries.[4]

Finally, we shared an implicit theoretical background, which was united by a common understanding of the concept of NSI, and mixed with the specific and diverse research subjects previously faced by each research team in our day-to-day academic activities in different national and regional realities.

The starting point of this research was not a solid and consolidated theoretical background. There was a diversity of views on interactions. The theoretical backgrounds for each of our research reports were prepared with a broad review of existing literature on interactions. This diversity of views, instead of being a weak point, was in fact a strong asset to our research effort. This diversity allowed the research to capture the mosaic of channels, modes, and forms of interaction prevailing in our 12 countries. This diversity also helped advance a theoretical view that incorporated the specificities of our 12 countries in a more general theoretical framework – an important challenge for this book.

Beyond this theoretical challenge, there is an important finding that first appeared as a new problem and in the end opened a new avenue for

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[4] In 2004–2005, a pilot project was conducted in Minas Gerais, Brazil – an adaptation of pioneering surveys on an immature NSI (Albuquerque et al. 2005; Rapini et al. 2009; Chaves et al. 2012).

our research: interactions between firms, universities, and research institutes must be investigated within a global context. Our empirical work in all countries always led us to international links that must be taken into account. The persistent reference to international links in our field work should not be a surprise. Classic studies of the economics of science and technology have suggested how science and technology has a tendency to overcome national boundaries. Nelson and Rosenberg (1993, p. 17) discuss this trend under "national systems and transnational technology," and stress that there is a tension between attempts to "implement national technology policies . . . in a world where business and technology are increasingly transnational" (p. 18). In our research, with our focus on the interactions themselves, the push toward international flows was uncovered many times.

In each country we did find fingerprints – more visible or less visible hints – of international flows that connect firms, universities, and research institutes among different countries: firms in one country that are connected with universities and research institutes abroad; foreign firms that have contact with research groups working within local universities or research institutes; and subsidiaries of transnational corporations with connections to universities or research institutes both in their home and host countries.

During our field work we collected enough evidence to trigger an impression that with our national focus – inevitable given the design of our research – we were capturing only part of a broader picture. Our research was lucky enough to collaborate during 2009 and 2011 with a project on Global Innovation Networks, led by Jo Lorentzen. This project, INGINEUS,[5] allowed three research groups[5] to work on the relationship between local and global interactions among firms, universities, and research institutes. This effort resulted in a tentative theoretical framework to deal with these cross-border flows. Our empirical work made us face a new theoretical challenge that pushed us to enrich our theoretical framework (see Chapter 8).

There were some differences between the approaches taken on each continent. Africa needed a theoretical framework able to deal with countries at different stages of development, including least developed countries. A specific concern about how to deal with innovation in the poorest countries is put forward by Lorentzen and Mohamed (2010): the lens

[5] Centre for Development Studies (CDS), India; Human Sciences Research Council (HSRC), South Africa; and Centro de Desenvolvimento e Planejamento Regional, Universidade Federal de Minas Gerais (Cedeplar-UFMG), Brazil, collaborated through the project Impact of Networks, Globalisation, and their Interaction with EU Strategies, 2009–2011 (INGINEUS).

necessary to grasp innovative efforts in these countries is not available in the existing literature on interactions – an understanding of innovation in these countries "requires an analytical apparatus we do not have" (p. 7). These reflections have an important implication for our research because "in many LICs [low-income countries] . . . firms are a relatively less representative actor" (p. 15). Rural livelihoods, agriculture, and health are subjects that have more importance, stresses Lorentzen. Starting from this point, Kruss et al. (2012) attempted to integrate the three levels of development of Uganda, Nigeria, and South Africa by using the "transition of phases" approach proposed by Sercovich and Teubal (2008) – a three-phase trajectory that fitted the positions of the three countries. The integration between Lorentzen and Mohamed (2010) and Sercovich and Teubal (2008) is fertile because it shows the differences among the interactions at each level of development, the differences between the actors and their size, and the implications for the elaboration of public policies for the transition between each phase. The results collected by the three studies in these countries capture empirically those differences (see Chapter 1).

The main question in Asia was how to deal with dynamic transformation – especially the recent catch-up process in South Korea and the fast changes taking place in China. These dynamic transformations demanded a theoretical framework within which the changes could be captured. In South Korea, for example, there were very specific dynamics between different institutional actors during the last three decades – public research institutes accounted for the key interactions with firms during the 1970s and 1980s, but investment in universities has grown since the 1990s (Eom and Lee 2009, pp. 501–504). Another example of institutional changes comes from China: the main modes of interaction during the 1980s – University-Run Enterprises (UREs) – are currently fading away in favour of horizontal university–industries links (see Chapters 2 and 4). These visible dynamic changes motivated Eun et al. (2006) to propose a framework based on the "absorptive capabilities" of firms and the stage of evolution of universities and their specific and changing roles – later defined by Liefner and Schiller (2008) as "academic capabilities." As the capabilities of firms, universities, and public research institutes evolve, the nature, the channels, and the reasons for the importance of universities to firms change. The empirical evidence collected by the teams from China, India, South Korea, Malaysia, and Thailand provides an array of dominant patterns of interaction, which expresses not only the fast changes in the region, but the differences in terms of stages of development and the push toward technological upgrading (see Chapter 2). In comparison with Africa, Asia's theoretical framework needed to deal both with differences in stages of development, size, and maturity of the NSIs, and with

the speed and scope of the changes taking place – China now, and South Korea earlier, show how the speed of these changes differentiates them from India, Thailand, and Malaysia.

Latin America is a more homogeneous continent. Mexico, Costa Rica, Argentina, and Brazil have a less dispersed level of development (they have all been in regime of interaction II since 1982), a more common set of problems, and a more homogeneous historical process – all are former colonies of Iberian countries (see Chapters 3 and 7). In contrast with Africa, the countries are more homogeneous and are at the same level as South Africa (Kruss et al. 2012, p. 519) – Mexico, Argentina, and Brazil share with South Africa similar problems related to the level of income inequality. In contrast with Asia, Latin America presents more uniformly stagnant growth. The stage of formation of the NSIs in Latin American countries is generally considered to be incomplete or "weak" (see Chapter 3). This diagnosis suggests that the formation of NSIs must go ahead and that interactions must change as underdevelopment is overcome. The theoretical framework elaborated by Arza (2010) is rich enough to provide an excellent snapshot of existing channels and flows of information in Latin America. This relative homogeneity may account for the feasibility of the continental econometric exercises summarized by Dutrénit and Arza (2010) and the matrices of interaction prepared for Mexico, Argentina, and Brazil (see Chapter 7).

The stage of the debates on the role of universities and their interactions throughout Latin America is captured by Arza's theoretical framework, which accordingly investigates how different channels of interaction may or may not be beneficial to universities. The model integrates the data collected in two surveys, and evaluates the risks involved in "commercial" and "services" interactions as compared with "traditional" and "bi-directional" interactions. This evaluation makes sense because it draws on the current Latin American distrust of prevailing modes of interaction, and demands an examination of their risks and benefits. One motivation for Arza's (2010) framework may be a suspicion that existing universities would be pushed to very early privatization of knowledge. This study, combined with other approaches, may be an important building block for a dynamic framework that takes into account the possibility of a transition from one dominant pattern of interaction to another pattern of interaction that is more sophisticated, more complex, and includes more feedback between universities and firms.

These three approaches show how different realities and trajectories demand a different lens for investigation. The richness of the empirical findings provided by these approaches – and sometimes their controversial interpretations – is shown in the chapters of this book. The empirical

findings are rich enough to question conventional wisdom and perceived truths. This new knowledge contributes to our effort to integrate those approaches into a more global view of the interactions between what Nelson and Rosenberg (1993) called "major institutional actors" of the NSI approach. Hopefully, our efforts will do more than fill gaps in studies on interactions between firms and universities in emerging and less developed countries. There are dimensions of those interactions that cannot be seen in the United States, Europe, or Japan. There are aspects and features of these interactions that could not have been seen if we had investigated Uganda, China, or Mexico alone. By combining our research in 12 countries in three continents, we have created something else – a more universal and dynamic view of the interaction between firms and universities in developing countries.

THEORETICAL BACKGROUND: STARTING POINTS

The theoretical background prepared by the three continental teams surveyed the literature on interactions. Lorentzen and Mohamed (2010) focused on the least developed countries in innovation studies and how they are discussed. Arza (2010) built her theoretical review on the pioneering works of Ernesto Sabato and authors within or influenced by the Triple Helix approach (Etzkowitz et al. 2000). Eun et al. (2006) built their proposal on transaction-cost economics and authors like Williamson (1985).

In common in all these works were Klevorick et al. (1995) and Cohen et al. (2002). Now, we are able to integrate their findings into a more dynamic framework: the snapshot captured by these pioneering papers may be interpreted as a sort of "provisional end result" of a long historical development – with the United States as the representative country for the regime of interaction III.

"Provisional" is used because technological development has not ended – for example, in adapting the questionnaire of the pioneering Yale and Carnegie Mellon (CM) surveys we included a new source of interaction: the internet. "End result" because there is history underlying each "source of information" and each "channel of knowledge."

The picture described by Cohen et al. (2002) may be considered an empirical representation of what the large literature on interactions between science and technology put forward between the 1970s and the 1990s. Cohen et al. (2002) helped organize our research work by pointing to three key issues for our previous investigations and for the international RoKS research project: (1) how are different fields of science and engi-

neering important for different industrial sectors; (2) what are the most important sources of information for innovation by firms; and (3) through what channels of knowledge flows do firms and universities communicate?

However, the theoretical background that supported investigations of interactions between universities and firms within the NSI in the United States is inadequate for the non-developed world. The most important reason for this limitation is that in the NSI in the United States (and in other mature NSIs) there are strong "major institutional actors" working: both large top-level universities (Rosenberg 2000), and a set of dynamic multidivisional and multinational firms with capabilities to monitor and to use science and engineering fields and to interact with those universities (Chandler 1990). These actors are the result of a long-term historical process, as both Rosenberg and Chandler point out in their books.

To deal both with underdevelopment (Furtado 1986, 1987) and with catching-up countries like South Korea, a dynamic framework is necessary. Because universities, firms, and the interaction between them are part of the conceptual framework of an NSI, this dynamic framework must deal with the specifics of NSIs at the periphery. These specifics include both the existence, nature, size, and quality of universities, and the existence, nature, size, capability, diversification, and variety of firms. Therefore, it is necessary to study both the evolution of universities and public research institutes and the evolution of firms. The interplay and interactions between universities and firms change over time, depending on the stage of development of both actors and the intensity of the links between them. Historically, there is a dynamic feedback process between these two formation processes (of universities and firms) that generates a variety of forms of interaction between universities and firms.

A QUESTION ABOUT METHODOLOGY

Our international research project prepared common research instruments – two questionnaires, one for firms and another for research groups, whether located in universities or in research institutes. Preparation of the questionnaires involved formal discussions between all teams. The meetings included the Milano Catch Up Meeting (September 2006), the IDRC Ho Chi Minh City Meeting (January 2007), and the First Latin American Workshop (September 2007). In addition, hundreds of emails were exchanged among the country teams, and valuable input was received from a patient and always helpful Dick Nelson. Informal conversations in Catch Up Meetings (since New York, May 2005) and in Globelics Conferences (since South Africa, November 2005), and specific academic

visits among researchers in this project, also helped shape these questionnaires. The format of the questionnaires is truly a product of international cooperation. It was a long learning process – we began to learn new things about interactions in our countries long before our field work.

It is important to understand how we developed our questionnaires. The questionnaire for innovative firms was based on the original questionnaires from the Yale Survey (Klevorick et al. 1995) and the Carnegie Mellon Survey (Cohen et al. 2002). They were adapted to our countries to reflect the present stage of development of our immature NSIs, which are distributed through regimes of interaction I and II (Figure I.1).

Questionnaire design was an important issue in our research. We followed four general principles: (1) adapt the questionnaire to handle the specific scientific and technological characteristics of immature NSIs; (2) focus the questionnaire[6] on the role of universities and public research institutes for industrial innovation; (3) maintain the flexibility necessary to include national differences in economic sectors (following International Standard Industrial Classification [ISIC] sectors) and academic disciplines (according to the Organisation for Economic Co-operation and Development [OECD] classification); and (4) keep as much comparability as possible with the original Yale and CM surveys.

Adaptation of the original questionnaires meant that: (1) our questionnaires were shorter and more focused; (2) the academic disciplines included in the questionnaires were different, because the science and engineering fields not mentioned in the CM survey are important for our 12 countries (veterinary, mining engineering, and agro-sciences); (3) new channels of interaction were included (technology parks and incubators, and the internet); and (4) universities and research institutes were investigated in two different questions (instead of being put together in one single question).

The second questionnaire was for research groups in both universities and public research institutes. The goal was to investigate the other side of the interactive relationship and to understand the impact of these interrelationships on group production (e.g., papers and dissertations) and the origins of the initiative that led to the relationship.

The samples were defined in a flexible way, according to relevant sectors and universities in the country. However, during our research, we used other research tools beyond our questionnaires: interpretations of available data (patents and papers); surveys (firms and universities); case studies of selected points of interaction; and historical studies. This combination of different research tools was very helpful. No one research instrument

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[6] Our survey corresponded to Section III of the Yale survey "The relationship of science to technology" and to Section III of the CM survey "Sources of information."

can capture everything because each instrument has its "blind spot." However, in combination, the instruments complemented each other.

The surveys were very informative, but they may provide only a partial image of the complete picture. For Latin American countries, for example, they help prepare matrices of industrial sectors and science and engineering (S&E) fields that show "spots of interaction" – not well distributed "points of interaction." However, when historical studies focus on these points of interaction, they unveil the history behind each one of those points and the long-lasting nature of those interactions (see Chapter 7). These historical studies also show how those sometimes scarce points of interaction are important for the economy as a whole.

The combined interpretation of results coming from different research tools informs a re-reading of our survey results, and highlights the importance of those points and how they matter for the economy. Historical studies show how important topics such as the process of state and nation building and social inequality are to understanding the social constraints for university creation and growth. University creation may be seen as an anti-elitist policy, and as such a policy goal to be confronted by existing elites (educated or uneducated).

Beyond the research tools used by our project, there is also information provided by the lack of data, by difficulties and obstacles to surveys application, and by the openness of firms and universities to our investigation. The conversations and negotiations between the different national teams about our research tools were also informative and truly enlightening.

A MORE GENERAL THEORETICAL FRAMEWORK

Since early 2007, research has taken place in 12 countries and there are now at least 15 research reports, 40 articles presented in international and national congresses and conferences, 28 papers in peer-reviewed journals, two special issues in specialized journals, and three books. The integration of the theoretical background provided by the NSI literature, the contributions from the 12 research teams, and the synthesis provided by the chapters in this book provide safe ground for a new step forward: an elaboration of a more general and universal approach to interactions between firms and universities. The notes in this section dialogue with the theoretical models from the study of university–firm interactions in developed nations and extend those models to the study of catching-up processes in developing countries.

Our research findings have stimulated us to rephrase our previous hypothesis about the small significance of universities for less developed countries. During this research we learned how to find and evaluate

interactions between universities, public research institutes (PRIs), and firms and society. The result is an improvement in our understanding of the relevance of universities in all stages of development and our ability to identify the lack of universities, and their limits in terms of size and quality, as constraining factors for development.

Six aspects are examined: (1) the role of universities as antennae of technological changes; (2) the importance of universities and PRIs since the early stages of development; (3) the ways firms and society at large act as sources of multiple demands on universities and PRIs; (4) the dynamics of interactions, and matches and mismatches as a structural phenomenon; (5) the historical roots of interactions and structural changes; and (6) the inclusion of cross-border interactions.

Connecting the Periphery to Technological Revolutions at the Centre: Universities as Antennae

The first building block is the role of universities as "antennae" of science and technology produced at the centre of the capitalist system. The nature of technological progress in capitalism was discussed by Marx (1867), who showed how the permanent revolution of technological basis is a key factor of capitalism. Later, Schumpeter (1939), Mandel (1974), and Freeman (1982) showed how technological revolutions, through long waves of capitalism development, shape and reshape the structures of the capitalist economy. The literature on interactions between science and technology in developed countries could be read as explaining how these technological revolutions are generated at the centre. Those technological revolutions repeatedly generated at the centre of capitalism are diffused throughout the whole world and impact the countries at the periphery of the capitalist system (Furtado 1986).

The impacts on the periphery of the waves of capitalist development change and reshape the challenges and opportunities for catching up.[7] This dynamic international technological framework is the context in which the universities at the periphery establish their first role. They are important channels to absorb knowledge generated abroad – to absorb knowledge from the centre of technological dynamics. The ability of countries at the periphery to access knowledge and technology from the centre is one important factor that changes the divide between the centre and the periphery: South Korea overcame underdevelopment, new capabilities acquired by firms and universities at the periphery changed their roles

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[7] For a discussion of technological revolutions at the centre and their impacts on a peripheral country like Brazil over time, see Albuquerque (2007, Section 2.2).

in the international arena. There is a specific dynamic that reshapes the centre–periphery divide, including what Marques (2014) calls a "boomerang effect" – improvements at the periphery have feedback effects on the centre. In sum, the technological revolutions at the centre and technological learning at the periphery create a dynamic transformation of the nature of centre–periphery relations.

Chapter 8 shows that, among the global links that connect firms and universities, links between domestic and foreign universities are important for the transformation of domestic "university capabilities" or "academic capabilities" (Eun et al. 2006; Liefner and Schiller 2008). PhD students sent abroad, research cooperation, and scholar visits are important channels for improving capabilities within domestic research institutes and universities. Following this line of thought, previous contact between a foreign university and a domestic research institute is a precondition for a domestic flow between a local university and a firm (or a farm or a local need in agriculture or health). Later, this initial role is reshaped and updated. Domestic universities must have international contacts and links – that over time become more and more institutionalized – to reach new knowledge that later they may diffuse to local firms, local institutions, and eventually to local subsidiaries of transnational corporations (TNCs).

This simplified dynamic international technological framework implies that the tasks of universities and firms related to knowledge absorption are ever changing. As the "Red Queen effect" suggests, sometimes it takes a lot of effort just to "stay in the same place" (Ribeiro et al. 2006, p. 90), just to preserve the existing technological gap vis-à-vis developed countries.

Although overcoming underdevelopment is possible and feasible, as South Korea has shown (Furtado 1992), it is a great challenge. Overcoming underdevelopment depends strongly on universities and firms and the interactions between them.

Universities and PRIs: Important since the Early Stages of Development

Universities and PRIs are one of the first channels to connect a country at the periphery to international flows of science and technology.[8] The first universities and PRIs in less developed countries are created with foreign teachers and native students who graduated abroad. As Richard Nelson has put forward, "in countries behind the frontier, universities often are key institutions in the building of capabilities in sciences and technologies because they provide a home, a stopping off point, and a source of

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[8] Other forms of early connections to developed countries are travellers, traders, and study abroad.

the transnational flow of people in science and technology" (personal communication, 3 August 2009).

The decision to create local universities and local PRIs depends on the level of nation and state building. The date of creation of the first (relevant) universities and PRIs therefore is important information. Latin American countries have in common a late onset of their universities and PRIs (19th century), which is highly correlated with national independence and initial organization of national and public finances.

Late development, by definition, means high levels of poverty, inequality and strong social problems such as slavery, ethnic segregation, and colonization. Therefore, since their formation, local universities and PRIs are confronted with great challenges, which determine a "dual role" for them. They must keep in touch with scientific and technological development at the centre while facing various new problems and issues (diseases, soils, plant varieties, and geologic and climatic conditions) that need specific investigations and might generate new scientific knowledge.

Furthermore, various tasks must be performed by universities and PRIs: teaching; training of human resources for public administration (especially at the beginning of nation-building processes) and for the creation of firms (e.g., state-owned infrastructure, and key mining and manufacturing sectors); diverse problem-solving tasks; and eventually (in the beginning) truly original scientific research (especially in agriculture and health).

Later, during the initial industrialization process, there seems to be a wave of institutional formation, with new PRIs and universities (at least faculties) created that may help to solve new (and more complex) problems. In the Latin American and African cases, we identify a combination of late industrialization and late beginning of local scientific institutions. However, both events are related to deep structural changes in society, which are a consequence of important political changes. Therefore, there is no automatic mechanism operating to push the process of institution building ahead. Given the potential anti-elitist nature of the process of university creation and expansion, social movements are also an important factor to stimulate the formation of new institutions.

The process of university formation is multifarious, therefore neither determinist nor automatic. There may be demands to solve societal needs (to fight diseases and epidemics), there may be demands from organized agricultural producers to face plagues or bugs that hurt harvests, there may be requests from mining sectors to upgrade mining techniques, and there may be demands from governments to provide tests for infrastructure building. But there may also be institutional building ahead of the

demand (after some state initiatives) that should foster the creation of new industrial sectors.

No matter the driving force for institution building, once created, universities and PRIs trigger a new process that has new actors, new demands, and new opportunities for the local economy and society. One important feature of this new dynamic is the attempt to preserve links with the evolving international S&T environment.

In this new dynamic, the enlargement of universities and PRIs and consequent diversification (so important, according to Figure I.1) is a difficult process with social resistance. The size, diversity, and quality of universities depend on various social variables like the reduction of illiteracy and universal access to basic and secondary schools. These variables in turn depend on other social variables such as income distribution and welfare conditions. Social constraints to university development are, therefore, causes of limitations in the role of universities for development – underlying causes of the "spots of interaction" identified in the matrices prepared for Latin American countries (see Chapter 7).

As universities and PRIs grow, their dual role becomes more complex. They must perform their role as "antennae" for the local society and economy in a broader range of S&E fields, as these fields grow in number and scientific complexity at the centre. As well, local demands and local research questions grow in size and complexity. This role as "antennae" changes over time, with new tasks put forward by technological revolutions at the centre. But this role exists throughout all development phases: compare the role of National Agricultural Research Systems (NARS) in the diffusion of Green Revolution Modern Varieties (GRMVs) (Evenson and Gollin 2003) with the creation of the Korean Institute for Electronic Technology (KIET) in South Korea (Kim 1997, p. 214) to help local (large) firms to enter the computer and semiconductors industries.

In the first meeting of the Catch Up Project (Columbia University, May 2005), Robert Evenson put forward a clear relationship between universities (or at least higher education institutions) and the diffusion of GRMVs. Countries without the beginnings of a university system, or more specifically, countries with "failed National Agricultural Research Systems," achieved no or very limited diffusion of GRMVs (with consequences for the pace of their industrialization process) (Evenson 2005, p. 1 and p. 3). Evenson and Gollin (2003, p. 758) argue that NARS and International Agricultural Research Centres (IARCs) "generally fill complementary roles." Evenson's remarks stress how PRIs are key for the diffusion of available international knowledge, and in the case of GRMVs this knowledge is public. Furthermore, Evenson associates those "failed NARS" with "failed states" (Evenson 2005, p. 1).

South Korea, now in regime of interaction III, is a good illustration of the catch-up process. Kim (1997) indicates how the South Korean government took the initiative in 1966 to create PRIs (Kim 1997, p. 84), ahead of any demand from existing firms. This type of state initiative was repeated in industries such as electronics (p. 207), and computers and semiconductors (p. 214 and p. 228) – in this case the PRI created was KIET. These South Korean state initiatives should be interpreted as part of a more general economic framework that, according to Amsden (1989), the South Korean state built to discipline both labour and capital.

The evolution of local universities means that their roles become more diverse (e.g., teaching in new areas, research in various directions, following diverse motivations, and demands for advice for public policy and public health). This point summarizes what Eun et al. (2006) call "capabilities of universities," later defined by Liefner and Schiller (2008) as "academic capabilities" – they are not static and show an evolutionary trend over time.

Finally, there is a specific dynamic between universities and PRIs. It is not possible to talk about universities and PRIs as if they are the same. One important difference between our questionnaires and the Yale and Carnegie Mellon questionnaires is the unfolding of one question on universities into two questions – one for universities and another for public research institutes. This new question came after an initial conversation during the first Catch Up Meeting (New York, May 2005), when Keun Lee made this suggestion, given the importance of public research institutes for the South Korean process. The combination of the interpretation of our questionnaires (see Chapters 1–6) with the historical evidence discussed for different countries, suggests a division of labour between these two institutions, both throughout countries and within each country over time. In the South Korean case, it is clear that the creation of PRIs was a short cut to overcome structural debilities with their universities. The speed of the process, and the specific roles of these PRIs in relation to firms, could not be performed by existing universities. Therefore, during the initial phases of South Korean catch up, interactions between firms and PRIs (with the leading roles by the PRIs) were important (Eom and Lee 2009, 2010). Later, as universities developed, they assumed new functions in their interactions with firms, leaving PRIs with other functions.

PRIs may begin the formation of domestic S&T institutions, and later change their roles as universities develop. They may also be instruments to articulate industrial policies with S&T policies. Eventually, PRIs may be transformed into universities.

Firms, Farmers, and Society: Multiple Sources of Different Demands on Universities and PRIs

Even in least-developed stages, there are demands on universities and PRIs to transfer publicly available knowledge from international networks to the country. Evenson (2005) shows how available public knowledge on GRMV could not be transferred to a set of countries given the lack of NARS. Similarly, health needs for poor populations cannot be answered given the scarcity of health professionals, mainly university-trained physicians.

In early stages of development, agricultural and health issues are there as unattended demands on universities and PRIs. In Uganda, according to Kruss et al. (2012, p. 525), "interactive activity was concentrated at a large, long established university based in the capital city, where emergent networks were evident. For the most part, these network projects were oriented to break poverty traps and to deal with problems of human development and the challenges of knowledge intensification of traditional agricultural activities to enhance productivity." Lorentzen and Mohamed (2010, p. 13) stress the dominance of those demands in comparison to issues related to industrial firms in the least developed countries.

This remark is important because during our investigation we dealt repeatedly with a focus only on university–industry links. Indeed, more developed countries (and more developed regions within a large and uneven country) also have these demands on health and agriculture presented to universities and PRIs that go beyond the strictly industrial dimension. One important feature of underdevelopment is heterogeneity – countries like India, Mexico, South Africa, and Brazil have within their borders regional inequalities that make their epidemiologic profile very specific, a combination of health problems typical of the poorest countries of the world (communicable diseases such as malaria and schistosomiasis) and health problems typical of richer countries (chronic diseases such as Parkinson's and Alzheimer's). Therefore, universities and PRIs should preserve this sort of broader relationship and interaction with society throughout all phases of development.

Firms depend on universities for trained human resources (e.g., engineers, chemists, biologists, and software professionals). Today it seems impossible to create new firms without any university-trained professionals in various industrial sectors and probably beyond a threshold size of the firm (given its engineering and managerial complexities). This is one long-lasting relationship between firms and universities, which is preserved throughout all development phases. This relationship may be overlooked by the traditional field of industrial economics.

As long as industrialization advances, new demands are presented to universities and PRIs, from tests to more complex problem-solving tasks and to the adaptation of more complex foreign technologies. There may be a self-organizing formation process for new sorts of interactions that unfold as industrialization processes grow.

Eun et al. (2006) emphasize the absorptive capabilities of firms and the specific dynamic that their growth determines. The growth of the capability of firms is correlated with the growth of the importance of universities to firms. Dynamically, this means that, as the capabilities of firms increase, new demands on universities and PRIs emerge.

New firms are created all the time. What kinds of firms are created and how long they will survive depends on several factors. Studies on the birth, survival, mortality, and growth of firms are important. The creation of new firms also highly depends on other social and political conditions such as: access to credit (public and private); educational conditions (the educational level of founders of the firm matter, because in certain industrial sectors university training may be necessary to create a firm); and the absence of social, colonial, or ethnic constraints (in Brazil, the Portuguese prohibited manufacturing activities until 1808, and in South Africa during apartheid "it was illegal for Africans to head their own enterprises or to engage in manufacturing activities," according to Terreblanche 2002, p. 379). This process of firm creation, like the process of university formation, also depends on broader social conditions. Gerschenkron (1952) showed that, for latecomers, industrialization is not an automatic process; on the contrary, it is a process highly dependent on institutional innovations such as banks (industrial and development) and state initiatives for firm creation in key sectors.

The vitality, sectoral nature, and spread of this process of creating new firms define the nature, intensity, and importance of demands on universities and PRIs. Therefore, industrial policies are very important for this process as a whole.

Finally, TNCs impact the whole process because they are a historical product of capitalist development at the centre and may (or may not, depending on industrial and public policies) help or constrain industrial development at the periphery (Amsden 2001). TNCs establish new channels of knowledge flows.

In an opposite direction, local firms may grow in size and capabilities and place new demands on local universities that cannot be answered by them. Thus, these local firms may establish direct contacts with foreign universities, both for complex problem solving and for technological upgrading – this is the case in China (see Chapter 4, Tables 4.8 and 4.9).

Interactions and Changes over Time: Matches and Mismatches as Structural Phenomenon

As suggested by Eun et al. (2006), to investigate interactions and their dynamics over time it is necessary to evaluate the capabilities of both universities and firms. As Figure I.1 shows, the sizes of universities and PRIs matter because thresholds of critical mass must be overcome. Figure I.1 may also have a qualitative interpretation: the quantitative steps taken by South Korea between 1974 and 2006, jumping from regime of interaction I to regime of interaction III, are related to qualitative changes related to entering new industries, especially information and communication technologies (see Kim 1997). These basic factors underlie the multifarious interactions between universities and firms.

The workings of the channels of knowledge flow investigated by Cohen et al. (2002) have a historical evolution. First, there is a process of change in university capabilities. Initially, universities and PRIs may provide human resources, testing, and simple problem solving (e.g., consultancy and technical assistance). Later, universities and PRIs become better equipped and their laboratories may be used by local firms. Finally, they take one step further and undertake research activities that substitute and complement research and development (R&D) by firms. Second, there is a process of change in the capabilities of firms. Initially firms may only use university-trained human resources, later they may look for universities and PRIs to solve technical problems, and as these problems become more complex, research issues may arise and R&D joint projects may become part of the agenda.

This double-sided metamorphosis is well illustrated by the South Korean experience. KIET was created to help firms access computer and semiconductor technologies, and provided information to firms entering these technology sectors while they improved their internal capabilities. As the internal capabilities of these firms increased, they were able to buy the institute (Kim 1997, p. 214 and p. 228).

An important finding of our research is the relevance of universities and PRIs even to low-technology sectors. For countries in Regime II (e.g., South Africa and Latin America), one research finding is that existing "points of interaction" have long-lasting historical roots: the mining sector and PRIs in South Africa (Pogue 2006; Kruss 2009b); agricultural products, iron, and steel in Brazil; iron and steel in Mexico; and agro-sciences and food industries in Argentina (see Chapter 7). These historical roots are illustrated by the mining sector: in South Africa (Pogue 2006) and Brazil (Carvalho 2002), faculties and universities were important to bring updated knowledge from developed

countries to existing local firms in South Africa, and to create new firms in Brazil.

There is a learning process, both by the firms and the universities, after the interactions begin. These relationships have a proper logic, and are a sort of spontaneous process. This internal dynamics of each point of interaction may involve shared knowledge, mutual trust, transfer of personnel between the two actors, and a better understanding of each other – a sort of logic that Williamson (1985) evaluated using a transaction-costs framework. The history of these interactions may be short lived or last longer. They may change over time, becoming more efficient and more productive for both sides. What our surveys capture are snapshots of interactions that have history behind them (unveiled by case studies of points of interactions).

Old and new tasks are combined and must be answered by local universities (there are different layers of demands, as new demands are added and the old ones are reshaped and restructured). Therefore, university–industry links are just part of the overall functions of universities, even in the interactive domain.

The diversity of forms of interactions between universities and firms may be further illustrated by the Chinese experience: as Eun (2005) has shown, academic-run enterprises and university-run enterprises (AREs and UREs) are specific forms of relationship in China. Eun et al. (2006) suggest that this mode of interaction is specific for a context in which academia and universities have stronger capabilities than firms. Financial conditions also matter because universities have access to state and to township and village resources that may be used to fund new firms that they create. This Chinese specificity, as Eun (2005) explains, has historical roots that can be traced to 1949, the foundation of the People's Republic of China. Eun mentions three peaks of AREs – during the Great Leap Forward, during the Cultural Revolution, and after Deng's reforms (especially the S&T reforms).

These remarks suggest that matching of universities and firms is an exception. The norm, especially during a catching-up process, is a mismatch between universities, PRIs, firms, and farms.

Because universities and PRIs have access to available international knowledge that is not available locally, they provide technological opportunities to existing and new firms. This form of technological opportunity is a specific feature of technological progress at the periphery. Compare this form of technological opportunity with those discussed by Dosi (1988b). These technological opportunities provided by local universities and PRIs may or may not be wasted, depending on the dynamics of firm creation and the capabilities of the firms. Over time, even when universities and PRIs are doing their job properly, mismatches with industries may take place.

New economic sectors in peripheral countries may be created after the first movements are taken by universities and PRIs. Thus, at least temporarily, there may be mismatches between the two actors.

As in the centre, in the periphery there are structural differences in the roles of universities, PRIs, and firms, which are a consequence of a division of labour within the NSI. These differences are translated into problems of timing, goals, and points of view. These problems are perceived by the actors as mismatches – and are well captured by our surveys.

Local dynamic firms may present demands that local universities cannot answer in the short term. This mismatch may stimulate local universities to find new connections with foreign universities and to upgrade their teaching and research capabilities. But this mismatch may push local firms to have direct contact with foreign universities. These contacts may have spillover effects on both local firms and local universities.

Subsidiaries of TNCs may need to strengthen the local academic capabilities of existing universities or local public research institutes to answer specific needs. Eventually, they may send employees to their headquarters for training in their R&D laboratories. This training may be useful both for their subsidiaries and for local universities – this employee may become a teacher or a researcher.

As in developed countries, there are, from time to time, conflicts regarding the role of universities and public research institutes around issues such as the nature of the research to be undertaken (basic, applied, a combination of both) and their relationships with firms and the private sector. These conflicts may be seen as part of the efforts to adapt institutions to new tasks and the new challenges put forward by the development process.[9]

There is a broad co-evolutionary process that involves matches and mismatches between universities and firms over time. This co-evolutionary process is subject to structural changes, and therefore is not a linear or smooth long-term process.

Structural Changes and Interactions in Historical Perspective

Social and political factors matter for the formation and growth of universities, PRIs, and firms – the whole process is neither a smooth process nor only quantitative growth. On the contrary, the processes depend on structural changes that overcome constraints and open new avenues for institutional formation and innovation. Examples of landmarks in these processes are national independence, abolition of slavery and ethnic

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[9] Richard Nelson, personal communication.

segregation, industrialization, democratization, and reformist movements for universal education. Waves of institutional formation seem to be correlated with these landmarks events.

Development is a complex and multi-causal process; therefore, the stress on the role of NSI for development does not in any way suggest a mono-causal approach. On the contrary, this research, while focusing on the specific building blocks of an NSI, informs a deeper understanding about how the process of university formation depends on other historical and political conditions (nation and state building) that underlie the creation of universities and PRIs. For example, the late onset of universities and PRIs in Latin America and in Africa seems to be correlated with Latin American and African late industrialization (see Chapters 1 and 3).

Our discussions and literature reviews help to differentiate at least three patterns in the formation of universities and PRIs: (1) failed states lead to failed universities and PRIs (Evenson and Gollin 2003); (2) states captured by elites (e.g., Brazil and South Africa under apartheid) or states that only "discipline labour" lead to limited "islands of excellence" (Amsden 2001; Terreblanche 2002); and (3) states with capabilities to indicate strategic areas for private investment lead to the dynamic creation of PRIs, guide the interaction of PRIs with firms by way of industrial policies, and overcome underdevelopment (Amsden 1989).

This differentiation, very introductory but illustrative of more general trends (deeper socio-historical currents), highlights the complexity of studying universities and their interactions. Indeed, there may be a great challenge for all countries in our research: how can democratic and participatory processes improve decision making about complex subjects such as the allocation of resources for science and technology? This would add a new building block to the framework of NSI: the relationship between democratic processes, public policies, and the maturing of NSIs.

The non-linearity of those processes, given the peripheral condition of the countries involved (with the exception of post-1990s South Korea) is also affected by the uncertain pace of technological revolutions at the centre. Given these technological revolutions, the whole university system must be re-adapted again and again, otherwise the technological gap in comparison to developed countries may widen. Technological revolutions at the centre determine another structural feature of the interactions at the periphery: the tasks of the educational system increase because old and persistent unsolved issues (e.g., illiteracy and communicable diseases) now must be tackled together with new issues (e.g., access to computers and internet, and teaching activities in new S&E fields, like nanotechnology and biotechnology). The nature of the whole process is related to structural changes: advances from one phase to another are related and caused by structural changes.

The Global Context in which the Interactions Take Place

The tension pinpointed by Nelson and Rosenberg (1993, p. 17) between "national systems of innovation and transnational technologies" was intensely felt during the implementation of our research. Certainly since 1995 the process of internationalization of capital has been deeply intensified. This intensification, sharper in the S&T realm, was combined with our approach to this subject: in many ways, our research teams had to deal with international flows connecting our "major institutional actors" across borders. The end result is a clear perception that we cannot deal with interactions without adding an important global context. The international flows and the international connections also have a dynamic dimension: they change the nature, types of flows, modes of interactions, and even the direction of the flows over time.

The presence of these international flows is so pervasive that it is no longer sufficient to mention TNCs and their impact – they need deeper investigation. The last chapter of this book suggests a tentative taxonomy to make sense of these international links. The TNCs investigated by our research teams have links with universities in their home countries: the firms investigated by Klevorick et al. (1995) and Cohen et al. (2002) contain TNCs whose headquarters are in the United States. Narin et al. (1997) had already shown how a global firm like IBM is able to use knowledge produced by US and foreign universities – our research captured part of this picture, the part where an IBM subsidiary had contact with a local university.

The diversity of possible links is large: Adeoti et al. (2010, p. 102) describe how Nestlé in Nigeria works with the Federal University of Agriculture, Abeokuta (UNAAB), and has contributed to its improvement. Fiat has a network of R&D departments distributed worldwide and an engineer working in a Brazilian R&D department may be sent to an Italian university with deep and long-lasting links with their headquarters for additional training. This engineer may return to Brazil and become a teacher in a local university.

TNC subsidiaries in peripheral countries may not have any links with local universities, but they have "indirect" links with foreign universities. Eventually, TNCs may establish links directly with local universities without local subsidiaries. TNCs must be taken into account when considering diverse and new channels of knowledge flow, and determining the specifics of new interactions at the periphery. For our research, it is important to understand how and why TNCs may define a hierarchical "internal division of labour" that combines contacts with local and foreign universities.

The tension between "national systems of innovation" and "transnational technology," as indicated by Nelson and Rosenberg (1993), has increased so much that now it is necessary to rephrase questions about local interactions between firms, farms, and universities across the world – these interactions might be seen within a context shaped by the beginnings of a global innovation system.

ORGANIZATION OF THIS BOOK

This book results from our tri-continent research effort. Its preparation began in Cape Town, South Africa, in August 2009, the concluding meeting of our RoKS project, and proceeded with an International Workshop that took place in São Paulo, Brazil, in September 2011, focused on the organization of this book. A first round of results was published: Africa published in the *Journal of Development Studies* (Kruss et al. 2012), Asia in a special issue of the *Seoul Journal of Economics* (Eom and Lee 2009), and Latin America in a special issue of *Science and Public Policy* (Dutrénit 2010). These first syntheses, grounded on country-based papers, fed our reflections and the organization of this book by continental and thematic chapters – facing new challenges put forward by our findings and our reflections about those findings.

The chapters of this book indicate the dominant patterns of different types of interaction, showing which pattern prevailed in each country and suggesting how these dominant patterns may change over time – as this introduction suggests.

This book is organized in three parts. The first part – "Interactions across regions at different stages of development" – has four chapters.

Kruss, Adeoti, and Nabudere, in the first chapter on Africa, focus on three countries at appreciably different levels of development: Uganda, Nigeria, and South Africa. The study examines the constraints and the features of identifiable cases of university–firm interactions, with the broad objective of ascertaining how to address the constraints and promote a more productive regime of university–firm interactions, appropriate to these African contexts.

Schiller and Lee, in the second chapter on Asia, present the cases of Korea, Malaysia, Thailand, China, and India. These five countries cover most of the differences that exist among emerging Asian economies in terms of duration of the catch-up process (early and late starters), size (large and small countries), and developmental policies (active and passive approaches).

Dutrénit and Arza, in the third chapter on Latin America, investigate

Mexico, Costa Rica, Argentina, and Brazil, discuss the results, and extract a set of features on the interactions between universities, public research institutes, and firms, particularly relevant to the relationship between channels and benefits.

Eun, Wang, and Wu, in the fourth chapter, show that a transition is going on in the mode of knowledge transfer from university to industry in China.

The second part – "Dynamic interactions: matches and mismatches over time" – has three chapters.

Pinho and Fernandes, in the fifth chapter, using data from our 12 countries, address the modes of relationship, the ranking of universities and PRIs among the sources of information, and the degree of success of this relationship.

Arza, De Fuentes, Dutrénit, and Vazquez, in the sixth chapter, conduct a comparative analysis of channels of interaction and derived benefits from interaction across our 12 countries.

Albuquerque, Suzigan, Arza, and Dutrénit, in the seventh chapter, present matrices of the interaction of the economic and industrial sectors with the science and engineering fields for Argentina, Mexico, and Brazil.

The third part – "Toward a framework of global interactions between universities and firms" – has one chapter. Ribeiro, Britto, Kruss, and Albuquerque, in the eighth chapter, suggest a typology to deal with global interactions and investigate empirically the international flows between firms and universities.

Finally, in a Postscript, O'Brien and Bortagaray analyse the experiences of our research programme and seek to conceptualize and quantify university–industry links in countries in Asia, Latin America, and Africa.

PART I

Interactions across regions at different stages
of development

1. Bracing for change: making universities and firms partners for innovation in sub-Saharan Africa[1]

Glenda Kruss, John O. Adeoti, and Dani Nabudere

Universities are traditionally known as centres of research and higher education. Globally, universities have undergone re-invention and renewal in tandem with societal change. In recent years, community development, and in particular the stimulation and spin-off of knowledge-intensive industries, has been proposed as a major contribution of universities to society. Etzkowitz and Chunyan (2008) observed that, while universities played a secondary role in early industrial society by providing trained personnel and basic research, universities now play an increasingly prominent role in the modern knowledge-based society, contributing the basis on which new industries and firms are built. Although this phenomenon has been pronounced in developed and newly industrializing economies, many developing countries are yet to realize significant change in the traditional view of universities as ivory towers of knowledge. Universities in such contexts largely remain institutions where knowledge is generated, transmitted, and preserved, with neither cognizance of its economic usefulness nor the aim of solving problems that would result in economic and social advancement. Developing countries that lag behind in the transformation of their knowledge institutions in response to the dynamics of intensely competitive industrial systems are characterized by relatively low capacity for the generation and use of economically relevant knowledge.

Theory and empirical studies show that technological innovation is the engine of growth, and the instrument of structural change in competitive economies (Solow 1957; Nelson and Winter 1982; Perez and Soete 1988; Romer 1990; Barro and Sala-i-Martin 1995; Kim 1997; Lall 2001). As

knowledge increasingly drives economic development, public universities are assumed to be critical sources for learning and innovation for firms in developed economies (Lundvall 1999; Mowery and Sampat 2005). There is now a substantial body of research and policy on university–industry links (UILs) and strategic alliances, and on the role of universities as key organizations of science and technology (S&T) systems within the national system of innovation (NSI) framework.

Increasingly, in developing economies too, universities are expected to become more responsive and play a direct role in knowledge-based economic and social development. Governments and higher education institutions are debating and borrowing policy to promote interaction between university and industry, and a literature on UILs in developing economies is emerging (Eun et al. 2006; Hershberg et al. 2007; Mathews and Hu 2007; Wong et al. 2007; Liefner and Schiller 2008).

These trends are increasingly pervasive in sub-Saharan Africa, where knowledge intensification is recognized as critical to address development challenges. The available evidence suggests that, in most African countries, the nature and pace of transformation of universities and industry have been grossly deficient to meet the demands of contemporary development challenges. In sub-Saharan African countries, UILs are weak and the challenge of building local technological capability is daunting (Oyeyinka 1997; Okejiri 2000; Adeoti 2002). For sub-Saharan African countries to achieve the economic transformation that would result in significant poverty reduction, it is necessary to address the current weakness in university–firm interactions as an important instrument of building technological capability.

However, there is evidence to suggest that approaches and policies appropriate to advanced high-income economies are adopted in an imitative manner, without understanding the specificities of the very different contexts of low- and middle-income countries. There is a trend to import and promote models and practices that evolved over decades in a few top American and British research universities in relation to high-technology sectors. In sub-Saharan Africa, scientific, technological, and interactive capabilities of universities and firms differ vastly, and it is impossible to ignore issues of human development, poverty reduction, and equitable distribution of wealth. New models are required that extend existing conceptual frameworks and take into account global changes in knowledge generation, diffusion, and adaptation in relation to the specificities of African contexts.

There is thus growing debate about the application of the innovation systems approach in developing countries, with attempts to refine the national innovation system framework to inform policy (Cassiolato et al.

2003; Farley et al. 2007; Lundvall et al. 2009). As yet, there is not a great deal of research on the role of universities in innovation and economic development that could inform contextually appropriate approaches and policy in sub-Saharan Africa. What does exist often engages with the challenges in aspirational and normative ways, proposing what should be and what could be (Myamila and Diyamett 2006; Etzkowitz and Dzisah 2007; Mwantimwa 2008). There has been little systematic research on the conditions of universities and firms and their potential for interaction across an NSI in the countries of sub-Saharan Africa (Muchie et al. 2003; World Bank 2009).

Therefore, in this chapter, we aim to examine the nature of university–industry interaction in distinct African contexts. Such analysis can inform the "bracing" for the change that is required to build the partnerships between universities and firms that can deliver technological innovation. We conceive such partnerships to be characterized by an exchange of knowledge that results in tackling economic and social challenges, and consequently results in economic progress and poverty reduction.

The chapter is based on a regional study of university–firm interactions in sub-Saharan Africa. The focus is three countries selected at appreciably different levels of development: Uganda, Nigeria, and South Africa. The study examined the constraints on, and the features of, identifiable cases of UILs, with the broad objective of ascertaining how to address the constraints and promote a more productive regime of UILs appropriate to African contexts.

CONCEPTUAL APPROACH AND METHODOLOGY OF RESEARCH

The conceptual framework used to guide the empirical study drew largely from the literature on innovation studies. The innovation studies literature has not engaged systematically with the conditions and context of Africa's development (Lorentzen and Mohamed 2010). The literature reveals a number of possible ways to categorize the NSI in countries at different levels of catch up (Albuquerque 2001; Bernardes and Albuquerque 2003; Fagerberg and Srholec 2008; Ribeiro et al. 2009), but most schemes employ a methodology reliant on patent and publications data. It proved difficult to adopt such schemes to categorize African countries, where patenting and publications levels are too low to allow for meaningful distinctions between individual countries.

To allow for a more fine-grained distinction of the heterogeneity of innovation and economic development in the three countries at the macro level, we adopted the systems evolutionary framework proposed

by Sercovich and Teubal (2008). The framework focuses on the interactions between firms innovation, knowledge systems, and policy learning in the catch-up process (UNIDO 2005). Building on the work of Imbs and Wacziarg (2003), Sercovich and Teubal posit that economies traverse three main "stylized" structural change-related phases as income per capita rises over time. Each phase has different mixes of diversity generation and specialization, leading to dynamic comparative advantages, manifest in new sectors and product classes that can successfully engage with global market conditions. The framework is suitable for our comparative purposes in that it does not propose invariant phases of development in a deterministic process, but represents a set of dynamic ideal type phases that vary across countries, sectors, and regions with distinct initial conditions. Transition between these phases is not automatic, but depends on the ways in which policy creates appropriate conditions to address system failures, strategic priorities, and latent opportunities of each phase. The framework was deemed particularly suitable because of its conceptualization of a "phase 0" that encompasses countries with initial conditions that may not yet have reached critical thresholds.

This macro-level framework does not provide specific tools for analysis of UILs at the meso and micro levels. For this purpose, the research was informed by a complementary approach originally developed for a Carnegie Mellon survey of UILs (Cohen et al. 2002), and adapted for use in Brazil (Rapini et al. 2009). The approach examines the sources of innovation and research and development (R&D) of firms, the knowledge intensity of different types of relationship, and the channels of interaction between universities and firms (see Introduction).

Evidence from two main data sources is presented in this chapter. First, there is a survey of firms in key regions and sectors in each country, which establishes their levels of innovation and R&D activity, the channels and modes of interaction with universities, and perceptions of benefits and constraints by firms. The survey sample in Nigeria included 139 manufacturing firms in one of the three main industrial clustering axes, home to at least 60% of Nigerian firms in number and value addition (Adeoti 2009). In Uganda, the survey included 36 small and medium firms in the agro-processing and biopharmaceutical sectors in five industrial zones of Kampala, the capital and most developed region (Nabudere 2009). The core instrument was adapted to explore whether indigenous knowledge sources played a role in firm innovation and interaction. Firm data for South Africa differed in that they were based on a fresh analysis of national datasets from an innovation survey (2005) and an R&D survey (2005–2006) that focused on the cooperation partners of firms.

Second, case studies were conducted of the interactions of selected uni-

versity networks with firms in a biotechnology sub-sector in which there was comparative national specialization. Interviews were conducted with heads of department, senior managers, and senior researchers. In addition, the analysis drew on contextual studies of the economy and national policy, and of indicators of economic development, higher education, and innovation systems in each country.

THE CHALLENGE OF KNOWLEDGE-BASED GROWTH AND INNOVATION IN THE THREE COUNTRIES

Overcoming Low-level Equilibrium and Establishing Threshold Framework Conditions: The Case of Uganda

Uganda demonstrates the impact of years of political instability on a resource-based economy that has not yet succeeded in diversification (Nabudere 1980, 1990; Bigsten and Kayizzi-Mugerwa 1999). The majority of citizens still live in rural areas, and are reliant on the resilience of the informal subsistence agricultural sector. It remains an agriculture-based economy that includes both subsistence and export-oriented agro-processing sectors. Over the past two decades, Uganda succeeded in breaking the trap of political instability, and is regarded as something of an African success story. This is attributed to sound macro-economic management and pro-market reforms, supported by proportionately very large inflows of official development aid, loans, and grants (ADB 2007; UNCTAD 2007; IMF 2008). There has been a limited diversification of traditional activities in production (UNCTAD 2007), but constraints and structural weaknesses remain (ADB 2007). These are high population growth, poor infrastructure, weak financial intermediation, and poor development of the agricultural sector. The innovation system is extremely weak and fragmented, and emerging S&T capabilities may be too strongly tied to foreign R&D interests (Nabudere 2009).

Historically, the establishment of universities in Uganda was a post-colonial process, an instrument to attain national independence, and to promote development and modernization in terms of nation building. The first national university was established as a college of the colonial university, and by the time it became a national public university, the path and model of a Western university had been firmly institutionalized. Uganda currently has expanded the number of public and private universities, but produces more social science than science graduates, and few post-graduates. Universities face financial constraints and have been forced to

embark on reforms, drawing on models of the entrepreneurial university to privatize and commercialize programmes, but have had little impact on the country's industrial development (Mamdani 2007; Nabudere 2008a,b).

In terms of its trajectory of structural change, Uganda continues to display strong features typical of phase 0, described in the systems evolutionary framework of Sercovich and Teubal (2008). That is, it is characterized by low-level equilibrium traps that are typical of many low-income countries and lead to economic and social stagnation at subsistence levels. A dynamic transition to conditions more typical of phase 1 is in process. The main feature is a wide variety of technical, organizational, and managerial experimentation and learning that develops innovative capabilities and competences of (predominantly small) firms in relation to products new to the firm or to the economy (rather than to the world) with selection largely at the firm level.

Establishing Framework Conditions for Knowledge-based Growth: The Case of Nigeria

In contrast, Nigeria clearly has made a transition from phase 0, in that the oil-dominated economy displays a degree of diversification and the beginnings of selection at the firm level, typically in small firms through experimental activities alongside traditional activities. Nigeria displays features of stalling in phase 1. Transition is partly constrained by unresolved low-level equilibrium traps, and partly by path-dependent structural weaknesses. These weaknesses arise from the impact of the oil-based economy and related industrialization, which is based on consumer industries reliant on imports that have little local content or value addition (Adeoti 2009). Nigeria has experienced constraints arising from political instability, and a complex succession of civilian and military regimes (Kilby 1969; Ekundare 1973; Forrest 1993; Ihonvbere 1993). Agriculture contributes the largest portion of the non-oil producing sector (Kasekende et al. 2007). The share contributed by services is relatively high, which is explained by the large informal sector, and by value-added manufacturing, which as a percentage of gross domestic product (GDP) is lower than the average in sub-Saharan Africa (UNCTAD 2007). Without sufficient investment and policy prioritization, the NSI is still very immature, and is highly disjointed in establishment, management, and operation.

Similar to the case of Uganda, the university system in Nigeria was initiated in 1948 to create a pool of human resources for the civil service of the colonial government. Concurrent with the first signs of the development of modern industry in 1952 and particularly post-independence, it was recognized that few Nigerians had knowledge of the managerial and technical

skills required for industrial production. The drive to improve the local supply of skilled labour saw the expansion of the number of universities in the 1960s and 1970s, which were claimed to be among the best in the British Commonwealth. However, as the economic crisis of the 1980s and 1990s weakened the capacity of the universities to generate knowledge, it became increasingly difficult for universities to reform and play significant roles as agents of economic development. Frequent unrest among students, industrial action on the part of academic staff, a decline in government support, the weaknesses of import substitution industrialization, and the incompatibility of African traditional knowledge with the knowledge generated in modern educational institutions, are all aspects that continue to shape the nature of university interaction with industry.

Accelerating Innovation and Firm-level Selection: The Case of South Africa

South Africa is typical of a country grappling with the challenges of traversing phase 2. This phase is characterized by the emergence of higher-level organizations in the form of new industries and markets, and the selection of products being primarily at the level of the firm, and largely governed by the market. The economy has become more diversified since the 1990s. Global exports indicate a comparative advantage in some sectors, but there is a predominance of "mineral-based items," so advancing the diversification of exports is still a key challenge (OECD 2007b, p. 27; Presidency, Republic of South Africa 2008). The expected foreign direct investment (FDI) inflows after 1994 have not materialized to any significant extent, which has widely been attributed to skills shortages and lack of infrastructural development. These structural deficiencies and systemic weaknesses relate to the economic and social divide, and the historical legacy of the unequal and segregated provision of education, health, justice, social services, and economic opportunities along racial lines. The highly unequal concentration of income leads to limited demand in home markets, and acts as a constraint on technological progress (Albuquerque 2007). The potential for parts of the emerging South African NSI to compete in the global knowledge economy is evident (NACI 2006; OECD 2007b). However, accelerated innovation and firm-level selection more widely across the economy are constrained by lack of skills and human-development demands.

   The South African higher education has long links back to the colonial period, and the first institutions were established in the late nineteenth century. Expansion of the system was driven by the early industrialization that accompanied the gold and diamond mining industries. The

system was strongly shaped during the apartheid period, when racially defined and unequally resourced institutions developed distinct missions as primarily research or teaching institutions. With the advent of democracy in 1994, the university system has undergone extensive institutional restructuring to address this historical legacy, expand access, and enhance responsiveness to economic and social development goals. An expansion of the higher education system is required for a transition to phase 3, particularly in relation to producing a large pool of graduates in the science, technology, and engineering fields. However, there are concerns that it may not be possible to expand significantly (Kahn et al. 2007; OECD 2007b). The system faces challenges related to: the low participation rate; the concentration of enrolment in social sciences and humanities; and an unresolved low equilibrium trap in basic schooling that restricts the pool of students available for critical fields of science and mathematics and leads to quality problems (Moja and Hayward 2000; Favish 2003; Fiske and Ladd 2004). These conditions shaped the scale and nature of interaction with firms promoted by new S&T policy incentives after 1994.

Distinct Developmental and Policy Challenges

Challenges in economic development, innovation, and higher education policy differ markedly between the three countries. In particular, they show marked differences from advanced economies that are more typically engaged in traversing phase 3, where specialization and firm selection begins to prevail, and innovation becomes a strategic priority. Most middle-income developing countries remain stalled in phase 2, with only a few having successfully made the transition to phase 3 (e.g., Korea or Taiwan). The framework provides a good basis to compare African countries at the macro level. It highlights their distinct trajectories and the specific structural constraints on, and latent opportunities for, knowledge-based growth, innovation, and the emergence of UILs.

FEATURES OF UILs

In this section, we analyse trends at the meso level. We draw on the firm data to consider whether and how the scale and nature of the interactions with universities differ among the three countries. Analysis begins with the case of South Africa, which is closest to the typical pattern of UILs in advanced countries that are traversing phase 3. We use this analysis to highlight the distinctly variant patterns of interaction in countries like Uganda and Nigeria, which are traversing into and through phase 1.

The Emergence of Networks: UILs for Innovation and R&D in South Africa

Typically, in phase 2, the challenge is to accelerate innovation. Firms increasingly attempt to enter competitive domestic and global markets by using innovation-related capabilities, and specialized selection emerges in some firms, including small and medium enterprises (SMEs), in some sectors. Interaction is typically with suppliers and users, but networks and cooperation become a strategic priority to take advantage of the capabilities of external knowledge partners such as universities, public research institutes, and technology centres. One weakness is that these are not well connected with, or co-evolved with, local knowledge and technology sub-systems.

Empirically, the patterns of interaction found in South African firms largely reflect this ideal type. Firms in general reported a relatively high rate of innovation in comparison with European Union averages (Blankley and Moses 2009). However, this type of innovative activity tends to be predominantly embodied in technology – through the acquisition of machinery, equipment, and software (54% of innovative firms) and intramural R&D (52%). Only 19% of firms engaged in extramural or outsourced R&D. The source of knowledge and technology to inform innovation is more commonly other firms, particularly user and supplier or customer relationships, or publicly available knowledge sources. University R&D is significant for only about 5% of firms. Universities are more significant for firms performing R&D, with a third reporting universities as their most common cooperation partner.

We see a set of technologically sophisticated firms interacting in networks with affiliated firms, suppliers, customers, and universities. The higher-level forms of organization that typically emerge in phase 2 are evident. A profile was constructed of the firms that innovate and perform R&D, and are more likely to cooperate with universities. A firm's propensity to draw on local universities – whether for innovation or R&D – is associated with larger firms, firms with higher levels of technological intensity, and firms more strongly linked to the high technology sectors. The propensity of small and medium firms to cooperate with universities is quite limited.

Strong sectoral differences are evident if we consider the proportion of firms in a sector that innovate, that innovate with interaction, and that innovate with university interaction (Table 1.1). Analysed a different way, the firms that cooperate with universities on innovation are more likely to be in the manufacturing sector (50% of the firms that cooperate with universities), followed by wholesale and retail (20.5%), financial and business services

Table 1.1 Comparison of innovation and R&D interactions by sector in South Africa

Sector	Innovation Survey 2005				R&D Survey 2005–2006		
	Total no. firms	Innovating firms	Innovating firms with interaction	Interaction with SA higher education	Total no. firms	R&D firms with interaction	Interaction with SA higher education
All firms	981	603	264	108	327	218	120
Manufacturing	367	266 (72.5%)	133 (36.2%)	59 (16.1%)	144	110 (76.4%)	67 (46.5%)
Financial and business services	146	84 (57.5%)	36 (24.7%)	14 (9.6%)	128	63 (49.2%)	26 (20.3%)
Mining	45	24 (53.3%)	11 (24.4%)	5 (11.1%)	14	14 (100%)	10 (71.4%)
Wholesale and retail	320	166 (51.9%)	54 (16.9%)	26 (8.1%)	4	2 (50.0%)	–
Agriculture	–	–	–	–	12	12 (100%)	7 (58.3%)

Note: Percentage represents the proportion of the total number of firms within each sector. For example, 72.5% of manufacturing firms innovate, 36.2% innovate with interaction, but only 16.1% innovate and interact with SA higher education.

(14%), and a few in the mining sector (4%). Innovating mining firms tend to outsource R&D, whereas financial and business services firms tend to conduct their R&D in house. Similarly, cooperating R&D firms are concentrated in the manufacturing sectors, with 92% of firms in high-technology sub-sectors reporting interaction with universities. Half of the firms performing R&D in the financial and business services sector cooperate, but only 20% of these firms with universities. Although there are a small number of firms in the traditionally strong mining and agriculture sectors, all firms report cooperation on their R&D activities – a high proportion with local universities, which reflects their strong historical roots (Kruss et al. 2009).

Higher R&D and innovation intensity in firms is associated with higher levels of interaction with universities for the industrial sectors, particularly mining. This suggests that these firms engage with universities to complement existing capabilities and enhance competitiveness. The financial and business sector firms that cooperate with universities have lower levels of R&D and innovation intensity than those that do not, suggesting that these firms tend to cooperate with universities to substitute for missing R&D capacity. Interaction thus tends to occur in a limited number of sectors where the fields of university research capabilities match the technological specialization and capabilities of the firms.

The form of interaction between universities and firms is typically formal, direct, and relatively knowledge intensive. It most commonly takes the form of a consultancy or contract to address immediate technology problems of firms, but technology cooperation networks are also found on a small scale (Kruss 2005).

Interaction with universities has benefits that enhance innovation and firm competitiveness. Firms that interact with universities reported considerably larger proportions of total turnover from innovative goods and services than do firms that cooperate with partners other than universities, and firms that do not cooperate at all. They also reported slightly higher levels of success in entering new markets or increasing their share in the market; higher levels of success in improving the quality of their goods or services; and increased capacity for production or services.

The data suggest that firms that innovate and perform R&D and cooperate with universities represent the "unstructured islands of innovation activity" in the total landscape of firms that is typical of countries traversing phase 2 (Sercovich and Teubal 2008, p. 33). The South African firm data illustrate a pattern of emergent UILs in key sectors to support firm-level selection activities; however, innovation and R&D networks are still not widely diffused across firms and sectors. This pattern contrasts with the Nigerian and Ugandan cases, where there is little match of firm demand and university capabilities.

## Experimentation and Incremental Innovation: Low Firm Demand for Interaction with Universities in Nigeria

Industrial firms in Nigeria are characterized by: a weak capability for the adoption, adaptation, and assimilation of largely imported technologies; low investment in R&D activities; and relatively high investments in new plants and replacement of aged production equipment, mainly sourced through imports. Typical of phase 1, domestic products suffer reputation disadvantages, innovative networks are missing, and markets for innovation products and services are limited.

Our survey confirmed that the levels of innovation and R&D in Nigerian manufacturing firms are low. The majority of firms are small or medium sized, and they most commonly conduct incremental innovation, using their own existing production processes to improve products or processes (74% of firms). Firms may innovate new to the firm (24%) or to Nigeria (16%), but very few report innovation new to the world (9%) (Adeoti et al. 2010). The R&D capability of firms is still weak, with very little investment assigned to formal in-house activity.

Almost 80% of firms reported that their own operations were the source for the suggestion and completion of incremental innovation projects (Figure 1.1). The most common external sources of knowledge were customers and competitors. Universities were in last place as sources of information and knowledge for new or existing innovation projects. They were less significant than publicly available external sources of knowledge, such as technical publications and reports, fairs or expositions, professional and trade associations, indigenous knowledge, and the internet.

When firms did cooperate with universities, the main channels of interaction were informal and publically available (e.g., publications and reports, and public conferences and meetings). These patterns were not unexpected in the early phases of selection and diversification, in which individual firms were involved in experimentation alongside traditional activities. Firms reported that they do not interact with universities because their own internal sources were considered sufficient, but equally, because of weak institutions and the lack of university capabilities. They generally perceived that universities had little to offer. Firms perceived the quality of research in the universities to be low, with the majority reporting that universities did not understand the firm's line of business and that the focus of universities was "big science" (Adeoti et al. 2010).

Unlike in South Africa, the relationship between universities and firms thus tends to be indirect. It is not formally structured, and it is not knowledge intensive. Incremental innovation relies primarily on the search and selection mechanisms of firms and their ability to assimilate publicly availa-
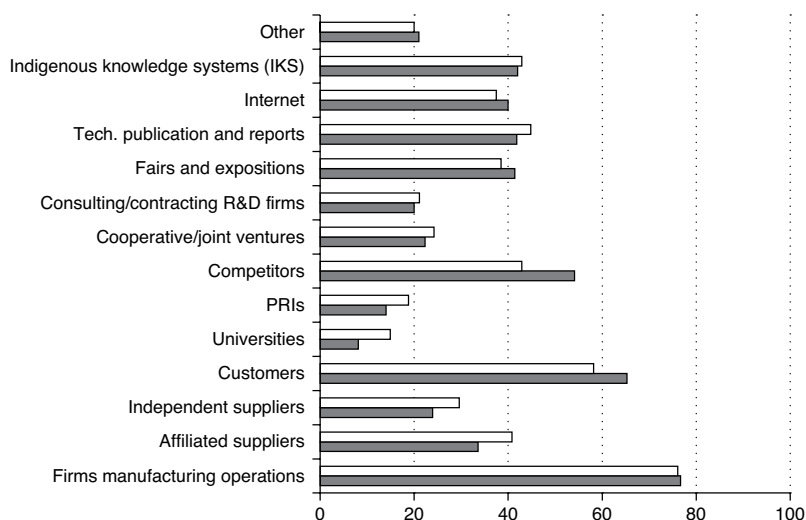
Note: White = for suggesting new projects; black = for completion of existing projects.

Figure 1.1 *Sources of information and knowledge (as percentage of respondents) for firms in Nigeria*

ble knowledge. Firm-level experimentation relies on internal resources and the insertion of the firm into value chains of affiliated suppliers, informed by customer demand. The innovation reported by the Nigerian firms relies on a "doing–using–interacting" mode of learning and knowledge acquisition (Jensen et al. 2007), which is characterized by internal processes of learning based on tacit knowledge and experience-based know-how acquired on the job. Also in contrast to South Africa, there is little evidence of a "science, technology, and innovation" mode of firm learning (Jensen et al. 2007). Therefore, there is little direct, formally structured or knowledge-intensive interaction with universities. The data highlight a major mismatch between the priorities and capabilities of manufacturing firms and the university sub-system, with little interaction or co-evolution of capabilities. A similar pattern is found in Uganda, with interesting variations.

Experimentation and Regulation: Firms Seeking Missing Internal Capacity

Uganda has relied on its peasant-based agricultural sector, and the economy has not diversified to a significant extent, in contrast with Nigeria. Foreign-operated multinational companies play a key role in
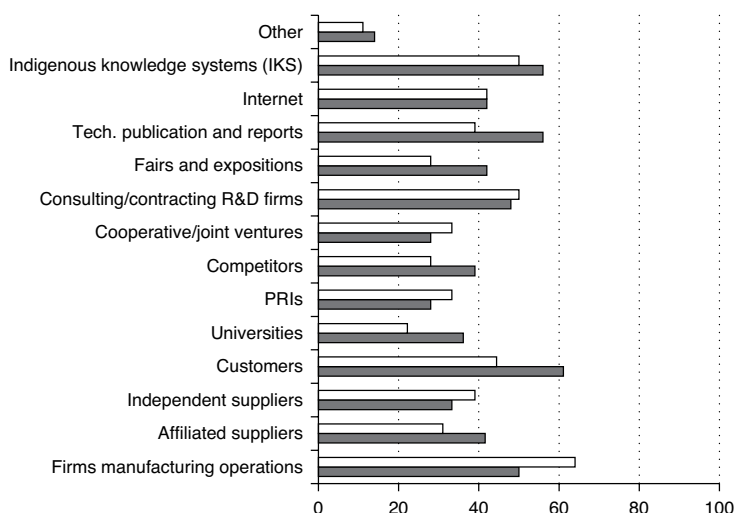
Note: White = for suggesting new projects; black = for completion of existing projects.

Figure 1.2   Sources of information and knowledge (as percentage of respondents) for firms in Uganda

industrial activity, and Ugandan-owned small enterprises find it difficult to survive the competition. The small sample of manufacturing firms is indicative of this trend. As in Nigeria, most of the innovative activities are incremental and are rooted in experiential learning within the firm. Product and process improvements are new to the firm or country. Firms invest very little in formal R&D.

Customers, indigenous knowledge experts, technical reports and publications, and the firms' own manufacturing operations hold sway as the main sources of information for suggesting new projects for the majority of firms (Figure 1.2). The completion of existing projects relies heavily on the knowledge accumulated by firms in the course of their routine operations, followed by indigenous knowledge sources, and consulting and contracting R&D firms. Less than a third ranked universities as generators of knowledge for their projects. As in Nigeria, this reflects the predominance of "doing–using–interacting" modes of knowledge acquisition, rather than firm learning that relies on S&T. In the perception of the majority of firms, universities are not sought out because they are concerned with "big science," and they lack understanding of the firms' line of business.

Where interaction with universities does occur, the most common channels of interaction are publicly available and informal. Only slightly different from Nigeria, these firms report a degree of direct but informal cooperation with university researchers: public conferences and meetings, informal information exchange, consultations with individual researchers, and publications and reports.

The very small group of enterprises that pursued interactions with universities to support their innovative activities were mostly intent on benefiting from new techniques and instruments, research findings, and laboratory facilities. Interviews revealed that these firms were seeking to compete in global markets. Quality control was an important motivation. The main objectives were: the performance of tests necessary to assure the quality of products and processes; assistance in quality control using university resources and public laboratories; and obtaining technological and consulting advice. These firms required external sources of knowledge to substitute for missing internal capacity. These requirements were primarily routine S&T and low-level capabilities of universities that could as easily be supplied by consulting R&D firms. Thus, as in Nigeria, the data highlight a general mismatch between firms and universities. Of note is the promotion of direct interaction with universities to support experimentation in a very small innovative SME sub-sector.

Two Distinct Patterns

The empirical data suggest two broad patterns of firm interaction (Table 1.2). The first is associated with the developmental challenges of traversing phase 2. Firms in key sectors are increasingly developing their innovation and R&D capabilities and interacting with universities in more formal, direct, and knowledge-intensive ways, to complement existing or substitute missing internal capacity. However, this activity is not widely diffused within sectors or across the economy. The second pattern is associated with traversing phase 1. There is a mismatch between firm demand and university capabilities so that interaction is largely informal, indirect, and not knowledge intensive.

There are variations to these patterns. The data from Ugandan show that the phases are not invariant, and that the transitions depend on the way policy creates conditions to address strategic opportunities, system failures, and latent opportunities of each phase. The following section considers how the development and co-evolution of policy capabilities shape the forms of UILs in a specific country.

Table 1.2   Two patterns of firm interactions

	Mismatch and indirect interaction	Interaction in key sectors, narrow diffusion
Main sources of innovation	"Doing, using, and interacting" (DUI) modes of innovation rooted in experiential learning within firm: own operations, customers, and competitors	"Science, technology, and innovation" mode alongside DUI modes, with main sources users and suppliers or customers, and publicly available knowledge
Diffusion of formal R&D	Low levels of firm R&D	R&D performing firms in some sectors
Types of relationship	Publicly available knowledge and technology	Consultancy and contracts, technology cooperation networks
Channels of interaction	Informal, indirect, and not knowledge intensive	Formal, direct, and knowledge intensive
Match of demand and capability	Mismatch between universities and firms	Universities and innovating and R&D firms in key sectors interact to complement or substitute capacity, but not widely diffused

THE EVOLVING INTERACTION BETWEEN FIRM INNOVATION, KNOWLEDGE SYSTEMS, AND POLICY

In traversing phases 0 and 1, horizontal policy mechanisms that can support the development of S&T institutions and threshold capabilities across the system are deemed more important than vertical policy mechanisms targeted at emergent competitive sub-sectors or at promoting UILs (Sercovich and Teubal 2008). The Ugandan pattern of interaction is shaped by the fact that, in a small country with a small number of universities, global funding and development agencies have directly encouraged the adoption of horizontal models of science, technology, and innovation policy. Donor agencies influence the policy of both governments and universities because they contribute significant proportions of national R&D funding (UNESCO 2007). At the same time, targeted policy mechanisms have grown niche specializations that depend on the involvement of universities in firm networks, and promoted new forms of direct and more knowledge-intensive interaction.

There is an emergent trend driven by government and foreign donor funding, and facilitated by intermediary organizations. The trend is to promote value addition in agriculture-related sub-sectors to grow export markets. For example, the government fostered a niche specialization in biopharmaceuticals based on indigenous knowledge of medicinal plants. A government export-promotion programme required that firms adhere to strict measures for chemical and quality control. To this end, it organized small firms that commercialize indigenous knowledge, and directly linked them with a university or public research institute. The firms interact with the universities to substitute for missing internal R&D capacity to be able to comply with international regulatory standards and promote global exports. This provides a positive example of co-evolution of university and firm capabilities stimulated by government policy intervention. However, across the Ugandan NSI, coherent and effective policy implementation mechanisms remain undeveloped, ad hoc, and fragmented. The questions are whether international policy is being adopted with sufficient understanding of domestic conditions and history, and whether it is possible for such targeted strategies to succeed in the absence of threshold conditions.

In Nigeria, in contrast, horizontal or targeted policy to support UILs has been largely absent until recently. Adeoti et al. (2010) argue that policy was deficient in identifying technological innovation as an engine of economic growth and development. Innovation has only recently been recognized in a new economic development strategy, and the introduction of a range of targeted sectoral interventions (Oyeyinka 2006). Historically, science, technology, and innovation were considered exogenous to Nigeria's economic development, and were acquired from outside by means of technology transfer. There have been few attempts to promote indigenous technologies and local sources on which new sectors could be based, in contrast with the Ugandan case. A "science push" approach, coupled with minimal public investment in S&T, is a major constraint to building capabilities and to creating the conditions needed for UILs.

South Africa faces a similar challenge to Uganda. It has adopted international policy models, but, as is increasingly evident, insufficient attention has been given to appropriating these models in ways informed by domestic needs and unequal human development conditions. Unlike Uganda, there is a well-developed set of targeted funding and incentive mechanisms and new institutions (e.g., government and industry research co-funding programmes, innovation-incentive funding programmes, sectoral incubators, and technology platforms) to drive UILs aimed at addressing problems of technology achievement. The US paradigm was a strong influence, and is evident in policy mechanisms to promote technology transfer, commercialization, and incubation in the high-technology

fields of biotechnology, nanotechnology, and information and communications technologies (ICTs). Recently, following OECD criticism of a lack of implementation of a commitment to "technology for poverty reduction," there has been renewed emphasis on a policy mission of "broadbased social innovation." Government and institutional policy learning is improving, but it is still a challenge to diffuse UILs across sectors and firms to support specialization. A major system failure is the lack of successful horizontal policy instruments to grow the education and training system. Therefore, critical skills shortages are a constraint on firms and universities, and on the development of the NSI.

Patterns of UILs are not solely shaped by the nature of firm demand. They are also shaped by national policies that promote S&T and an NSI within the context of global trends and influences.

RESEARCH AND INTERACTIVE CAPABILITIES FOR INNOVATION CAPACITY

The Nigerian and Ugandan surveys highlighted the perception of firms that universities do not have the capacity to meet their needs. However, in all three countries studied, there are instances of knowledge-intensive networks that signal latent opportunities for interactions. It is important to investigate what is emerging, and what conditions and capabilities in universities facilitate these networks. In this section, evidence is presented from micro-level case studies. In Ugandan and Nigerian universities, we look at interactions in agro-food processing, a sector that has received policy priority given the high contribution of agriculture to GDP in both countries. Health biotechnology is examined in South African universities.

University Support for Incremental Innovation and Productivity in Agriculture

In Uganda, two newly established regional universities displayed virtually no evidence of interaction with firms, given a lack of research capacity. Interactive activity was concentrated at a large, long-established university based in the capital city, where emergent networks were evident. For the most part, these networked projects were oriented to break poverty traps, address problems of human development, and encourage knowledge intensification in traditional agricultural activities to enhance productivity. There were emergent creative attempts to use technology for local economic development. As well, there was evidence of collabo-

ration with indigenous knowledge generators and users in the informal sectors, such as small-scale farmers based in cooperatives and community organizations.[2] The role of the university in these networks matches the firm mode of incremental innovation, and is not strongly related to basic scientific research or knowledge generation. A key role is testing and quality assurance to support conformity to international standards. The university is typically involved in training, extension and advisory work, field trials, and monitoring of the adoption of new technologies. Such technology transfer and research diffusion activities have a long tradition, although they may now take new, more knowledge-intensive forms.

Many of the projects are beset by problems of sustainability, given their reliance on donor project-based funding and the dearth of core government funding. The establishment of university incubators, science parks, and technology transfer offices is evidence of the direct importation of interactive mechanisms from advanced economies that assume there is a viable industrial sector with innovation capabilities. It remains to be seen how successful these emergent efforts will be to commercialize and disseminate new technologies generated within a university. It will also be interesting to see whether the local conceptualization of science parks and incubators will be informed by the nature of the specific demand for incremental innovation and technology adaptation and diffusion by Ugandan firms and other productive agents such as communities, cooperatives, and farmers.

Building the University Research System and Technology-transfer Mechanisms

The first of three universities studied in Nigeria was an established large traditional university with a highly qualified academic staff aiming to transform into a postgraduate institution. The second was a young specialized federal land-grant university established as part of a move to promote modernization of agriculture. The third was a young technology university aimed at academic degree programmes in engineering and related fields to address the local industrialization. The universities rely strongly on (inadequate) government funding, and foreign donor funding is not sufficient to have a strong impact. The case studies illustrate the impact and effects of the structural deficiencies and system weaknesses typical of phase 1 within universities: acute shortages of resources; paucity

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[2] For example, trials of an integrated pest-management technology that uses indigenous knowledge in a United States Agency for International Development (USAID)-funded consortium that includes American universities, Ugandan public research institutes, nongovernmental organizations, and a community cooperative that now includes 1300 members from 12 villages.

of laboratory, science, technology, and engineering research and training capabilities; scarce cooperation and innovation networks; and the poor reputation of domestic products and services (Sercovich and Teubal 2008). These require horizontal policy interventions to enhance research capacity and research infrastructure.

In general, interaction with firms tends to operate in the interests of higher education, and is formalized primarily through industrial work experience and training schemes for students, or sponsorship agreements with large firms. Most firm-oriented interactions were informal, were effected through former students, personal ties, and professional associations, or involved consultancy services in relation to product analysis or processing of key crops such as cassava. These activities support the incremental innovation processes of the firms.

University research is generating adaptations of technology to suit local conditions, but these are often in advance of market demand. For example, research on postharvest technologies and food processing has led to a long list of applied research outputs that are not diffused to small firms and farmers: yam processing and utilization, fermentation technologies, varieties adapted to cultivation in the local climate, solar energy designs, or cost-effective and sustainable organic agriculture systems. There are no mechanisms to disseminate this technology to firms, farms, or small-scale producers, or to support university commercialization, so these achievements typically remain hidden or locked into the institution. One reason is the historical over-reliance on importation and foreign technology, which translates into veneration for imported goods and skills, and becomes a constraint on local knowledge generation and technology transfer. As in Uganda, the universities have recently put into place interface mechanisms such as research centres, business development units, and centralized laboratory services, which may enhance technology transfer. Similar to Uganda, the universities do display emerging evidence of creative structures that work with small firms, farmers, and local groups to transfer research that can enhance productivity in agriculture, that can potentially open new value-added niche sectors for export, and that build their research base. Such instances can be studied systematically, nurtured, and replicated to develop interactive capabilities alongside scientific capacities.

Fostering Networks in Targeted Sectors in South Africa

Biotechnology policy in South Africa represents a state-driven attempt to promote key firms and lay the basis for a new sector or industry. The challenges are vast because biotechnology is in its infancy, and is faced with

limited research and technology capacity, a virtually non-existent industrial sector, and gaps in the value chain (Gastrow 2008). The first set of cases was located in a historically disadvantaged, relatively young, moderately research-capable university with strengths in niche areas, including biotechnology. Interaction primarily took the form of university-based spin-off micro-enterprises that offered bioinformatics consultancy services to foreign customers and clients. The second set of cases was based at a long-established, historically advantaged, well-resourced university with strong research capability and reputation. The cases all involved "frontier science" research, new to the world, but directly related to the human development health needs of South Africa and sub-Saharan Africa: HIV/AIDS vaccines; tuberculosis; and heart disease and hypertension. Drug, vaccine, and device development is proceeding at various stages through trials to the market.

All of the firms involved are foreign, whether interacting in the role of sponsor, customer, supplier of services, or partner in a start-up company. Key gaps in the local biotechnology supply chain drive cooperation with foreign firms: local capacity for producing vaccines, even trial quantities, has been eroded; few internationally compliant and certified laboratory facilities for monitoring trials exist; the lack of local venture capital means that investment partners are sought abroad; and the small size of local demand drives the search for foreign partners to assist with access to global markets. These cases illustrate the challenges of developing conditions and capacity for science-led firm selection, and of creating an emergent new product class. The fragile links within the NSI need to mature over time. The fledgling local productive sector is not able to take advantage of the latent opportunity inherent in existing research and knowledge-generation capability. However, it is unlikely that university-led commercial ventures can drive the process without a core local productive sector with key capabilities along the value chain. It is significant that some South African universities do have levels of scientific production that are sufficiently strong to attract global firms as business or research partners.

A DIFFERENTIATED POLICY APPROACH TO PROMOTE UILs

The chapter examines the role of universities in knowledge-based development in low- and middle-income countries, particularly in sub-Saharan Africa. In a globalizing world, there is no case to argue that sub-Saharan African is exceptional, but systematic analysis of the conditions and

capabilities of universities, firms, and interaction can provide insights informed by their "important peculiarities" (Altenburg 2008).

The framework of Sercovich and Teubal (2008) was under specified, and required conceptual refinement in relation to UILs as the unit of analysis. This was addressed by means of a complementary analysis of the nature of the channels of interaction. In considering the role of universities in economic transformation and poverty reduction in sub-Saharan Africa, the framework developed here highlights a significant degree of heterogeneity between countries that is commonly muted or missing in the research literature. Two broad patterns of interaction are distinguished, linked with the challenges of traversing distinct phases of structural change, but, in each country, shaped by evolving policy learning and university capabilities. The nature of UILs in South Africa is clearly more direct, formal, and knowledge intensive than in Uganda and Nigeria. Nevertheless, policy advances and university-level interventions in Uganda have stimulated the emergence, albeit on a small scale, of new more knowledge-intensive forms in specific sectors, which are not as evident in Nigeria. These potentially allow for universities to play a role in a more dynamic transition from phase 0 to phase 1, whereas in Nigeria universities play less of a role, in a stalled transition through phase 1.

Stronger analytical refinement and more systematic research in a wider range of countries covering more sectors are required to broaden and enrich the study of university interaction in sub-Saharan Africa. However, we believe that the attempt to link patterns of UILs at the meso and micro levels to analysis of the structural conditions, systemic weaknesses, and latent opportunities of dynamic phases of knowledge-based economic growth can yield insights to inform more appropriate policy interventions. As Sercovich and Teubal (2008, p. 12) propose:

> The point is engaging less in viewing the domestic development issues in the light of the experience of successful catching up countries . . . and more in assessing the latter's experience in the light of the specific circumstances of the countries that fail to catch up, with due attention paid to initial capability endowments.

In the following section, the insights from the empirical study are used to outline a differentiated set of strategic policy tasks as a starting point for "bracing" for change, and promoting university–firm partnerships in each country.

PROMOTING INTERACTION WITH SMALL-SCALE, INFORMAL, AND COMMUNITY-BASED PARTNERS

The strategic policy development task for Uganda is how to promote mutually beneficial university interaction with small-scale firms, farmers, informal sector producers, and community-based cooperatives in a context in which threshold conditions are not yet in place. Rather than being imitative of practice in developed countries or strongly driven by foreign donor agendas, policy frameworks and university-level interventions need to be more strongly informed by emergent local practice and by the specific priorities of the phase of structural change and economic growth. University interaction should be primarily aimed at supporting incremental innovation, value addition, and productivity in the agriculture sector, which provides the livelihood for 80% of the population. Fledgling initiatives provide models to inform government funding and incentive mechanisms. Horizontal policy reforms of basic financial, political, and educational institutions are as significant, if not more, than micro-level interventions such as science parks that have a limited reach to a small number of firms. A key policy challenge for the university system is to extend science, technology, and interactive capabilities beyond the capital region, to the new universities in other areas.

Building the S&T System

The strategic policy task for Nigeria at this point in time is different in emphasis from that of Uganda. The dual challenge is to build the S&T system to enhance confidence in the capabilities of local academics, and to identify and nurture new forms of technology transfer that can promote research utilization and build interactive capabilities to open up the knowledge locked in to the universities. Mechanisms to turn around the high reliance on licences and royalties to the advantage of local learning and technological capabilities are required. The key role of universities relates to technology transfer, adaptation, and dissemination to support experimentation and incremental innovation on the part of local firms, small producers, farmers, or community enterprises, and to enhance productivity and value addition in the agricultural sector, which remains highly significant. Simply providing direct incentives to promote innovation is unlikely to tackle the system failure embodied in the existing mismatch between universities and firms, if the universities do not have the infrastructure, scientific, and interactive capability to respond to firm demand.

Toward Targeted Policy Intervention

In South Africa, the need for horizontal policy to build the S&T system and to strengthen and diffuse scientific capabilities remains a priority. However, targeted strategic policy intervention is equally important to strengthen nascent priority sectors, and there is evidence of such attempts. A range of interventions is required to deal with specific contextual challenges: greater security and seamless links in public funding cycles; incentives to attract specialized high-level skills; local private venture capital and investment agencies; and enhanced capacity of government departments and public funding and service delivery vehicles to implement programmes more effectively. The promotion of university-based commercial ventures is only possible in some universities and some sectors in an immature system of innovation. Institutional policy interventions should proceed with extreme caution, unless they are linked with priority sectors with potential comparative advantage. Policies to promote collaboration and networks that build on and diffuse existing small-scale innovation activity are important for universities to develop.

Bracing for Knowledge-based Economic Transformation in Africa

As Juma (2006) observed, a new economic vision for the African region, expressed at the highest level of government, should focus on the role of knowledge as a basis for economic transformation. Doing so will entail placing policy emphasis on emerging opportunities such as renewing infrastructure, building technological capabilities, stimulating business development, and increasing participation in the global economy. A caution was raised at the beginning of this chapter, against imitative and aspirational adoption of the promise of UILs in economic transformation. If Nigerian, Ugandan, or South African universities adopt models of firm interaction, technology transfer, incubators, or science parks uncritically and uninformed by systematic analysis of sectors and firms in their own contexts, they may not succeed in achieving their goals.

There is a vast literature documenting "best practice" for UILs in developed economies. Based on detailed analysis of country-specific conditions and of existing firm and university capabilities and patterns of interaction, it is possible to select the most appropriate kinds of interventions, mechanisms, and organizational structures to tackle the strategic policy task, and to address local priorities in a more sustainable way.

2. Are university–industry links meaningful for catch up? A comparative analysis of five Asian countries

Daniel Schiller and Keun Lee

Knowledge creation and innovation are the key sources for economic growth in the long run, and the underlying learning and innovation processes are increasingly organized in an interactive way within innovation systems in different spatial (global, national, and regional), sectoral, and technological scales. As a result of the interactive nature of learning of innovation, the interface between science and industry became more permeable in general and university–industry links (UILs), which also include government research institutes (GRIs), became a particularly important mode of knowledge transfer. Although the general importance of this transfer channel is not debated in the literature, the focus of this chapter is on a context-specific conceptualization of UILs in latecomer countries, and a more fine-grained understanding of their contribution to economic and technological catch up. Mazzoleni and Nelson (2007) have already argued that research at universities and public laboratories is of importance for catch-up processes due to their potential to create indigenous technological and scientific capabilities. However, conceptual frameworks and empirical studies still refer predominantly to developed countries with full-fledged and mature innovation systems and, within this group of countries, to cases from the Anglo-American context. This limitation is problematic in two ways.

First, there are quite different institutional arrangements for science–industry knowledge transfer if UILs in the context of different countries and innovation systems are compared. The formalized transfer based on open innovation modes via patents, licences, or publications seems to be a typical arrangement in the context of the United States (US). For Japan, Branscomb et al. (1999) found that the innovation system had its own characteristics of UILs based on "informality." These relationships were

not covered by frequently used criteria like number of patents and licences and led to the delusive conclusion that Japanese universities played only a minimal role in economic development. For Germany, Schmoch (1999) revealed that most UILs were based on contract research, short-term consulting, and predefined problem solving, but that these interactions were taking place on a very regular basis. A major reason behind this phenomenon might be the focus of the German innovation system on incremental innovations in medium-high-technology manufacturing sectors in contrast to the orientation toward radical innovations in cutting-edge technologies in the US (Schiller 2011). Thus, David and Foray (1995) and OECD (2002) insisted that institutional arrangements among the actors of an innovation system were products of an evolutionary process and not the results of rational choices. In a similar way, Liu and White (2001) argued that to compare national systems of innovation (NSIs) one should pay due attention to the country-specific distribution of actors, the links among them, and the underlying institutional frameworks.

Second, researching the role of UILs in latecomer countries requires additional conceptual modifications beside the general need for more context-specific institutional and evolutionary approaches. Learning to assimilate and to improve acquired technologies (Kim 1999) and building technological capabilities (Lall 1992) and academic capabilities (Liefner and Schiller 2008) are the most important roles of innovation systems during the catch-up process. They are therefore called learning systems by Viotti (2002). Foreign companies and their affiliates play a much more prominent role, and the majority of new knowledge and technologies is acquired from extra-regional sources (Ernst 2002; Revilla Diez and Berger 2005). With regard to indigenous innovation capabilities, innovation systems in latecomer countries are characterized by a fragmentation of actors and their links (Intarakumnerd et al. 2002). Some actors are still missing or incapable of contributing to innovation activities, and embeddedness and trust among these actors are not yet sufficient to support the evolution of strong linkages.

Finally, the state is playing a distinct role in building successful innovation systems in latecomer countries (Yusuf and Stiglitz 2001). Basic investments in the innovation infrastructure still have to be made by the public sector. Therefore, Arocena and Sutz (2000b) have proposed an *ex ante* approach with a focus on system building instead of an *ex post* approach based on system analysis. The conceptual part of this chapter will reflect on the specificities of innovation systems in latecomer countries by grounding the research on the debate about absorptive capacity and technological as well as academic capability.

Against this background, it is the aim of the chapter to assess in a com-

parative way to what extent UILs are a meaningful vehicle for catch-up processes in five Asian latecomer and catch-up countries, to explain the differences in UILs among the five countries, and to give policy recommendations on the enhancement of UILs during catch-up processes. In particular, the chapter addresses the following research questions conceptually and empirically:

(1) In what way are technological capabilities of firms and academic capabilities of universities and GRIs interlinked during the catch-up process?
(2) Which institutional arrangements and collaboration modes are chosen for UILs in the five Asian countries?
(3) What are the outcomes and benefits of UILs in the five Asian countries?
(4) How do UILs differ among regions and sectors in the five Asian countries?
(5) In which countries are UILs already a vehicle for catch up, and how can UILs be strengthened in the future?

To answer these research questions, we conducted interviews, case studies, and quantitative and qualitative analysis using a questionnaire survey and in-depth interactions with policymakers and practitioners. Surveys were carried out in Korea, Malaysia, Thailand, China, and India. The sample of countries includes a first generation catch-up country (Korea), two second-generation countries (Malaysia and Thailand), and the two largest emerging economies in the world (China and India). China was also an example for a transition economy. By looking at these five countries, we cover most of the differences that exist among emerging Asian economies, in terms of duration of the catch-up process (early and late starters), size (large and small countries), and developmental policies (active and passive approaches). Teams of scholars from these five Asian countries conducted the international comparative study (see Introduction to book). The sample sizes compiled by each country team are shown in Table 2.1.

This chapter provides a comparative perspective on the main results of the country teams, which are published in the final technical report of the project (Lee et al. 2009), a short summary article (Lee and Kang 2011), and in a special issue of the *Seoul Journal of Economics* (2009). The authors of the individual country reports are: Keun Lee, Hyun-Dae Cho, Boo-Young Eom, and Raeyoon Kang (Korea); Rajah Rasiah and Chandran Govindaraju (Malaysia); Patarapong Intarakumnerd and Daniel Schiller (Thailand); Jong-Hak Eun, Guisheng Wu, and Yi Wang

Table 2.1   Sample size of surveys conducted in each of the five countries

No. interviewed	Korea	Malaysia	Thailand	China	India
Firms	600	361	6031	302	462
University researchers	2395	–	72	203	735

Note: In Thailand, existing data from innovation surveys of firms and interviews with university professors were used.

Source: IDRC survey results reported in Lee et al. (2009).

(China); and K.J. Joseph and Vinoj Abraham (India). Comparative results from the Latin American teams can be found in a special issue of *Science and Public Policy* (2010). The individual results of the country papers are not repeated in detail, but selected findings that contribute to the main argument are extracted and interpreted.

CENTRAL ROLE OF CAPABILITIES FOR UILs AND CATCH-UP PROCESSES

Absorptive Capacity and Learning via UILs

A central term in many studies about technological upgrading and learning in catch-up countries is absorptive capacity, i.e., the ability of a firm to identify, absorb, and understand technical knowledge that allows for the introduction of products and processes that are new to the firm (Cohen and Levinthal 1990). Absorptive capacity is itself determined by many factors, some internal to the company (e.g., internal research and development [R&D] activities, qualification and experience of management and workforce, company size, and company age), some external (e.g., market environment, access to capital, public R&D infrastructure, and government support). Internal factors alone are not enough to explain learning and innovation. In this debate – theoretically and empirically – the role of public research organizations (PROs), which comprise universities and GRIs, as alternative sources of knowledge has been somewhat marginalized: in contrast to the academic discussion about science-based industries, university spin-off firms, or entrepreneurial universities that focus on industrialized economies, it seems, at least, that the role of universities in latecomer countries is less central to economic upgrading and technological progress. Most studies focus on absorptive capacity in relation to foreign direct investment or trade

and international company networks. The contribution of universities is merely education.

Education is the most basic requirement of any technological upgrading (Hobday 2000; Lall 2000). Tertiary education, in contrast to primary and secondary education, becomes important as soon as firms move beyond the stage of carrying out low-wage production functions and start producing more sophisticated products or using technology-intensive processes. Especially when firms start setting up in-house R&D they need university-trained employees (Wong 1997; Lall 2000). Public R&D receives more attention than tertiary education as it sometimes plays a crucial role in latecomer strategies (Kim 1991; Lall 1998).

Very recently, however, both academics and policymakers have shown a marked interest in the potential direct role of universities in latecomer countries in upgrading and learning. Governments in latecomer countries have started to reform their higher education systems and academics have begun to be interested in the contributions of universities to upgrading. However, the direct involvement of PROs in the process of technological upgrading is rather demanding.

Proximity as a Prerequisite for UILs

Barriers for an efficient knowledge transfer across the science–industry interface are discussed by taking the five dimensions of proximity identified by Boschma (2005) as a starting point. He proposed that either too much or too little proximity may be detrimental to interactive learning.

Organizational proximity refers to the challenge of crossing organizational borders, which brings uncertainty and opportunism. UILs are necessarily crossing such borders because they are external to the firm and the university. Thus, control mechanisms are needed to ensure ownership rights, particularly intellectual property rights, which might be set up in a formalized way (e.g., via contracts), and require a sufficient level of organizational capabilities on both sides. Social proximity can serve as a substitute for organizational proximity to a certain degree. Trust-based relations could be an alternative way to control for opportunistic behaviour. However, this proximity needs time to evolve and a lack of trust between science and industry is expected to exist in latecomer countries because they did not interact a lot in the past.

Institutional proximity is a particularly problematic issue for UILs. The institutional background and the related incentives and aims differ largely between science and industry. An alignment between objectives, cognition, and realization of profits has to be negotiated to ensure mutually beneficial UILs. A science system with low academic capabilities, and

a high need for external funding from private sources, is at risk to sell out the long-term aim of achieving academic excellence for short-term financial benefits. Spatial proximity is not a value in itself for innovation and learning, but may provide mutual trust in localized innovative milieus, and a shared knowledge base due to externalities and spillovers of knowledge production. The combination of a strong local network of innovation actors with selected but often critical external links to excellent partners in other regions is expected to be the most efficient spatial configuration for learning and innovation. In latecomer countries, the science and the economic sector are often jointly located in a limited number of core areas. Although this is beneficial for UILs to take place, it is also a limitation for the decentralization of economic activities. If development strategies for the periphery are limited to satellite industrial parks, there will be a lack of academic partners that provide highly qualified labour and potentials for UILs. If universities only are relocated to peripheral locations, their graduates will migrate back to the core regions due to a lack of employment opportunities, and the university will not be able to exploit the cognitive and monetary potential of UILs.

Finally, cognitive proximity is the most important factor to enable interactive learning and innovation. A complementary knowledge base with diverse, but complementary, capabilities is needed to ensure a sufficient level of absorptive capacity and novelty at the same time. In latecomer countries, knowledge gaps among the actors are expected to be rather big, or the knowledge bases of the actors are similarly weak in early phases of catch up. Foreign firms are often too advanced for local universities, whereas local small and medium enterprises (SMEs) do not possess any capabilities for upgrading and innovation. Thus, only a few larger local firms are expected to be able to interact with local universities. In the following section we will discuss how technological and academic capabilities contribute to the extent of the knowledge base.

Technological Capabilities of Firms

For more than a decade, terms such as technological capability, technology accumulation, learning, absorptive capacity, and innovation strategies have been used to describe and to understand the assets and the changes internal to the firm that form the basis for technological upgrading (Lall 1992, 2000; Bell and Pavitt 1997). These terms have in common that they draw attention to the fact that firms have an active and sometimes conscious role in the process of upgrading. Contributions dealing with these terms point out that two types of success factors influence these processes: the internal capabilities of the firm and the external environment (Lall

2000). The internal capabilities of the firm are made up of several factors that allow for assessing the potential merits of a new technology, for acquiring, implementing and learning to use it, and for understanding it. The single most important factor for this is the internal R&D activities of the firm. According to Cohen and Levinthal (1989), internal R&D is the basis not only for creating knowledge but also for absorbing knowledge.

The external environment of a company contributes positively or negatively to its efforts to acquire and master technology:

(1) Some factors that constitute internal absorptive capacity are strongly linked to the external environment (e.g., human capital). In all countries, formal education organized through schools and universities is a public domain. The skills and qualifications of employees are, thus, largely determined by the education system, and only in-house training is left for deliberate company action. Public policy may more directly influence a firm's internal capabilities, for example, by giving tax exemptions or other subsidies to firms that carry out R&D.

(2) Governments are responsible for creating legal and institutional conditions that encourage firms to invest in their knowledge base (e.g., protection of property rights, fiscal stability, and openness to trade).

(3) Governments can help to create links between firms or between firms and other actors that provide a basis for knowledge exchange and learning.

For the case of latecomer firms in emerging economies, Dutrénit (2004) has put forward the very convincing concept of a non-linear transition of capabilities that are needed to develop a simple knowledge base for fractional innovation activities, in contrast to a complete knowledge base with strategic capabilities for a comprehensive orientation toward innovation. She argues that, during early stages of capability building (i.e., operation and basic innovation capabilities), different qualities of accumulation activities are important when compared to those needed during the transition toward advanced and strategic innovation stages. At the firm level, technological dimensions are more dominant at initial stages, whereas organizational capabilities, the coordination of learning, and the management of knowledge become relatively more important over time. In addition, innovation cooperation at the regional level is becoming more important, whereas an appropriate incentive regime, factor markets, and institutions for technological development need to be put into place by national and regional governments.

Academic Capabilities of Universities

This section discusses how universities could fulfil their extended role in the process of technological upgrading in latecomer countries. As argued by Eun et al. (2006), the two main views in the recent literature are based on the situations of the developed West and are problematic for application in latecomer countries. The core idea of the Triple Helix model (Etzkowitz et al. 2000) has minimum relevance for some of the latecomer countries that tend to inherit mature industries from the advanced countries to produce standardized products. The New Economics of Science (Dasgupta and David 1994) has a similar problem in terms of pertinence for latecomer countries as it assumes that universities make scientific breakthroughs and provide generic knowledge upon which industry bases its trivial applied research. Instead, the research capacity of universities in many latecomer countries is backward, and they often devote their resources to undergraduate education that mostly uses knowledge that is imported from advanced countries. It is our view that neither the Triple Helix nor the New Economics of Science provides a precisely realistic platform for understanding UILs in latecomer countries. A new theoretical framework such as the one proposed by Eun et al. (2006) is needed. They observe that there are diverse modes of UILs and the UILs in each country tend to take a certain mode depending on several country- or sector-specific factors. Eom and Lee (2010) likewise focus on the distinctive determinants and performance impact of the UILs in latecomer countries.

The term "academic capability" was introduced by Liefner and Schiller (2008), and a conceptual framework relevant for the context of latecomer countries was proposed. Academic capabilities are defined as the set of functional skills and organizational ability of a country's higher education institutions to carry out their extended role in the process of technological upgrading and learning. The extent of academic capabilities can be measured by the complexity of sub-sets of functional and organizational capabilities. Functional capabilities of academia comprise teaching, research, and direct interactions with industry. In addition, a functional integration augments the academic tasks in a synergetic way through research-oriented teaching or research and teaching consciously oriented toward industrial and societal needs (e.g., technological knowledge in high-tech sectors, or agricultural extension in rural areas). Organizational capabilities refer to budgeting, management, and institution building within PROs that provide the incentive structure for UILs by performance-based funding schemes, university autonomy, an entrepreneurial attitude, a development periphery for outreach activities, and clear regulations and promotional benefits for UILs.

Following Lall's (1992) framework of technological capabilities, the complexity of capabilities can fall into the categories low, intermediate, or advanced. The category "low" indicates that the level of activities – in quality or quantity – is not sufficient to foster the process of technological upgrading. As long as the universities' activities fall into this category, an input from the higher education system that could complement knowledge absorption from other sources is absent. Functional and organizational capabilities are classified as "intermediate" whenever partially stimulating effects on technological upgrading can be expected. "Advanced" activities have a clear and obvious impact on technological upgrading. They demonstrate effective ways of knowledge generation and knowledge dissemination, or they significantly improve the organizational effectiveness of the higher education system.

The level of the academic capabilities of a country's science system is strongly linked to its companies' technological capabilities, because its contributions are crucial for technologically advanced business activities. Highly qualified graduates bring new knowledge into their companies and, thus, are a necessary element in upgrading strategies. University research may set a basis for innovation and direct problem-solving assistance to companies. These close links between education, science, and industry are at the core of the well-established concept of the interactive innovation process (Kline and Rosenberg 1986). To create sufficient academic capabilities, there is a need for external public investment in higher education that is linked to clearly defined objectives for the development of higher education and technological upgrading. In latecomer countries, it is too early to pull back public funding from higher education and to push them toward finding their own funds when their academic core functions and their economic value are still limited. Nevertheless, internal organizational capabilities must be concurrently aligned in a way that is most suitable for the upgrading of academic functions.

Propositions about UIL Patterns in Asian Latecomer Countries

In this section, a set of propositions about UIL configurations in Asian latecomer countries is presented. These propositions refer to the modes of UILs, their outcomes, regional and sectoral differences, and the overall role for economic and technological catch-up processes. However, most of the Asian countries that are analysed in this chapter are more emerging economies than real developing countries. Therefore, they might be less comparable to some of the other cases from Africa or Latin America.

Importance of different UIL modes
The level of intensity and the modes chosen for UILs in Asian latecomer countries are expected to depend to a large degree on the stage of the country in the catch-up process and the associated level of technological capabilities of firms. At an "early stage," firms tend to have few in-house innovation activities or are not seriously involved in innovation and upgrading at all. In addition, they face diverse problems in production and management. Thus, they may only have a need for consultancy services from universities for solving small-scale problems. Often, universities do not have high academic capabilities either. At the "medium stage," some firms tend to establish in-house R&D laboratories and become involved in some R&D activities. However, they encounter difficulties and have a need for certain specific R&D targets or objectives for which they resort to help from external partners such as PROs. For this reason, these firms tend to rely more upon UIL modes like contract research and joint projects. Only at the "mature stage" do firms command strong in-house R&D capabilities and thus feel less need for more interaction with universities, but they rather tend to pursue more open science channels like papers, conferences, and informal interactions. For example, firms in the US tend to have their own R&D capability and thus have less need for contract research or joint projects with PROs.

Various kinds of governance modes and channels could mediate the knowledge flow between science and industry. Based on research by Eun et al. (2006), Arza (2010), and Schiller (2011), five scales seem to be particularly relevant for the characterization of UIL modes. They comprise the governance mode (open innovation via the market – closed innovation via hierarchical arrangements), the degree of directness (direct contact – organizational involvement), the scope (short-term problem solving – long-term open-ended, research-based – teaching-based), the motivation of the academic partner (intellectual – economic), and the motivation of the industrial partner (proactive exploitation of knowledge resources – passive use of existing knowledge resources). These scales are not dichotomous, but should be understood as continua between their respective extremes.

The resulting UIL patterns are country-, firm-, and sector specific and depend on diverse factors that include among others: (1) capabilities (technological and academic) of firms and PROs; (2) willingness of, or incentives and pressure on, PROs and firms; (3) sector-specific factors (sectoral innovation systems or technological regimes of sectors); (4) country- or NSI-specific factors such as the existence of intermediaries and the reliability of intellectual property rights (IPR) regimes; and (5) multi-scalar interdependencies and co-evolutionary relationships among them. For

example, if academic institutions have unique or strong R&D capabilities, they have to choose whether to internalize the resources (starting start-ups) or externalize them (transferring the resources to firms). The choice between internalization and externalization is like the make or buy decision in transaction-cost economics. When there is an effective technology market in operation, or manufacturing firms command high absorptive capacity, the researchers would just transfer or sell their technology to these firms. This would be the case of typical developed economies, especially when transaction costs are low. However, PROs might want to establish their own companies if the external environment is not suitable for the externalization or the manufacturing firms do not have reliable capabilities for commercializing the technology due to low absorptive capacity (Eun et al. 2006).

We suppose that the following configurations of UIL prevail in Asian latecomer countries, but that they are strongly affected by the dynamism of the catch-up processes and pushed toward a greater degree of diversity by contextual factors like place-specific institutional environments. Due to a lack of personal and institutional trust among science and industry, and a lack of organizational capabilities, we expect that closed arrangements via hierarchical arrangements and direct interactions are of importance. The low level of technological capabilities should be in favour of UILs with the aim of short-term problem solving if a particular problem in the production sphere occurs. Teaching-based UILs might dominate due to the prevalence of teaching in developing country universities rather than research. Firms might be more interested to use existing knowledge resources in a passive way because they lack the capacities for interactive and joint innovation activities. Due to funding pressures or low personal incomes, the academic partner might be lured into the economic exploitation of its (still limited) knowledge resources too early and therefore miss the opportunity to use UILs as an intellectual lever. Without doubt, this set of UIL configurations, which is expected to dominate in Asian latecomer countries, would be dysfunctional in several ways and would limit the expected outcomes of UILs.

Outcomes of UILs

In an interactive innovation process, the capabilities of cooperation partners should complement each other in a mutually beneficial way. However, the R&D capabilities of innovation actors in Asian latecomer countries might be too limited to enable such complementary interaction. Instead, firms might look for R&D resources at universities as a substitute for their lacking internal capabilities – low absorptive capacity is the barrier for this transfer channel to work efficiently. However, this might be only true for

SMEs in Asian latecomer countries, whereas large advanced local firms and foreign firms might possess capabilities that exceed those of local universities. In this case, it is even expected that knowledge transfer might run from industry to science. For example, engineering departments might get access to the latest production technologies of foreign firms. In such a case, the main incentive for firms to enter UILs is the exclusive access to highly qualified graduates and the customized training that is provided in jointly designed study programmes. Contrary to the usual knowledge flow from science to industry, the upgrading of academic capabilities of universities by firms is expected to be an additional outcome of UILs in Asian latecomer countries. This is especially true if advanced local firms or foreign firms are involved in the projects.

In these cases, the benefit for the university is obviously an intellectual one, but it is expected by Arza (2010) and Schiller (2011) that pure economic rewards for the academic partners might dominate in Asian latecomer countries. The reasons behind that expectation are limited or even reduced university funding by the responsible government agencies and low salaries for individual scientists, which increase the quest for monetary rewards. As well, academic and technological capabilities of the partners are either similarly low or knowledge gaps are too big to enable mutual learning. Thus, there might even be a risk that universities enter into entrepreneurial activities before their academic core is sufficiently developed. Thereby, the science system is at risk to lose its independence and cognitive capacity. Long-term impacts of UILs on learning and innovation are expected to remain low.

Regional and sectoral differences

A concentration of UILs in core regions in Asian latecomer countries is expected. Only these regions will be able to provide a sufficient critical mass of advanced firms and PROs to form meaningful innovation networks via UILs. In peripheral regions, UILs are expected to be limited to a few societal outreach activities, for example in agriculture, or firms may try to contact spatially distant scientific partners if they have any needs for UILs at all.

In developed countries, UILs are most important in high-tech sectors with a scientific knowledge base. In Asian latecomer countries, high-tech sectors are not expected to be the most meaningful industry for these interactions for two reasons. First, high-tech firms in Asian latecomer countries are often affiliates of foreign firms that do not perform their critical technological activities in the respective country, or have established partners in their home countries. Second, universities are not able to provide state-of-the-art knowledge for innovative breakthroughs in these sectors.

Instead, the technological capabilities of advanced domestic firms and the academic capabilities of the best local universities are sufficiently similar to enable UILs to exist in traditional medium- and low-tech sectors, where technological demand is limited to adapting technologies and improving production processes.

Contrary to findings from studies in developed countries that UILs and innovation collaboration, in general, are particularly relevant for SMEs, it is expected for less developed countries that large-sized firms are more likely to be active in UILs. SMEs in Asian latecomer countries are expected to lack the most basic technological capabilities and internal innovation activities to enter into UILs. Intermediate capabilities and a sufficient level of absorptive capacities are only achieved by larger firms that may have some initial internal R&D activities. In the following two sections the empirical findings from five Asian countries are analysed against this background.

HISTORICAL ROOTS OF UILs IN FIVE ASIAN COUNTRIES

From an evolutionary economics perspective, the configurations of NSIs, and the routines and capabilities of its actors, are highly path dependent and slowly changing over time. Therefore, a brief overview of the history of institutional backgrounds for UILs is provided by exploring their roots within their respective NSIs.

Korea

One of the most important characteristics of the Korean NSI is the "twin dominance" of big businesses (Chaebols) and the government, which also implies the relatively weak role of the universities and SMEs (Kim 1993; Lim 2006; Choi et al. 2007). For example, universities employ around 70% of the doctorate in Korea, but conduct only 10% of the total research in the nation, whereas the Chaebols employ 20% of the doctorates and conduct 77% of the research (OECD 2008a). In addition, as of 2005, 40% of researchers and 52% of PhD researchers belonged to the top 20 firms (MOST 2007). While big-business groups have dominated the NSI of Korea through their large in-house R&D since the mid-1980s, it was the government and GRIs that initially led the NSI of Korea during its early take-off period in the 1960s and 1970s. In the 1970s, Korea was in transition from light to heavy and chemical industries, but its national R&D base was weak. The Korean government promoted national R&D capacity by

establishing GRIs: a number of GRIs were established based on the Special Research Institute Promotion Law of 1973 in the fields of machinery, shipbuilding, chemical engineering, marine science, and electronics.

Noticeably, from the mid-1970s, Chaebol firms started to grow rapidly with diversification or entries into heavy and chemical industries. Afterward, the government played a significant role by providing a number of big firms with some privileges such as bank loans and access to foreign exchange. Even in the 1980s and 1990s, the Chaebols were aided by government-led public–private research consortia to achieve key R&D goals, with examples of TDX (a system of telephone switches), memory chips development, and digital TV projects (Lee and Lim 2001; Lee et al. 2005). According to a study by OECD (2003), Korea is the only country where GRIs rather than universities have a relatively greater role in national R&D.

In contrast to GRIs, universities have played a minor role in boosting R&D performance of the private sector in Korea. Big private firms rely more on foreign knowledge sources than local sources and universities. They hire quality scientists and engineers from abroad or acquire technology in collaboration with foreign partners. Kim (1993) argued that the lack of interaction between university and industry, which is due to the teaching-oriented nature of Korean universities, is one of the greatest weaknesses of Korea's national system.

Research has been given increasing priority in universities in Korea since the 1990s. Only since then has the ranking of Korea risen in terms of the number of Science Citation Index (SCI) papers written by university professors – Korea ranked 19th in 1996, with universities accounting for 83% of the contributions (Lee 1998). From the late 1990s, the policy agenda has shifted toward promoting the entrepreneurial role of universities.

The enactment of the Technology Transfer Promotion Law in 2001 symbolized this transition of interests toward knowledge industrialization. This law prescribed that public universities should establish units or institutions, such as Technology Licensing Offices (TLOs), which were in charge of technology transfer and training of specialists. Promotion of industry–university cooperation obtained more momentum as the universities began to establish the so-called "industry–university cooperation foundation" in 2004 after the enactment of the Industrial Education and Academic-Industry Cooperation Promotion Act in 2003. However, with this law, the intellectual property rights of the research outcomes of university professors began to belong formally to universities, whereas in the past, individual professors tended to file patents as their personal ownership. As of 2007, 134 universities had established industry–university cooperation foundations (dedicated centres for the facilitation of UILs founded under

the Industrial Education and Academic-Industry Cooperation Promotion Act) within their campuses, out of which 60% (80 universities) had TLOs. The number of TLOs increased rapidly, especially in 2004 when 43 were newly established. There were only 32 in 2003 (KRF 2007).

This discussion indicates that the knowledge industrialization that involves universities is a recent phenomenon that has not progressed much. It is interesting to examine its impact on firm performance and to compare the results with those from advanced or mature countries with a longer history of collaboration. According to a study by Eom and Lee (2010) using innovation survey data from 2000 to 2001, collaboration with universities does not significantly enhance the probability of innovation success, and has not led to sales increases but only to the increase of patents. This is in contrast to the results of European case studies conducted by Belderbos et al. (2004) and Faems et al. (2005).

Malaysia

The Malaysian government has implemented explicit policies since the early 1990s to stimulate UILs. Following the Action Plan for Industrial Technology Development (APITD) of 1990, the government launched the Malaysian Technology Development Corporation (MTDC), Malaysia Industry–Government Group for High Technology (MIGHT), the Intensification of Research in Priority Areas (IRPA) grant, and a number of other broader organizations to support UILs.

As part of the plan to innovate and commercialize research findings, the government increased the allocation for R&D and commercialization of technology to MYR1.6 billion (MYR1 = USD0.3) under the Eighth Malaysia Plan (2001–2005) compared with MYR1 billion under the Seventh Malaysian Plan (1996–2000). The government also launched the Second Science and Technology Basic Plan, which strongly advocates NSI reform toward a network-based system of interactions between innovation actors during 2001–2006. The government also added a science fund under the Ministry of Science Technology and Innovation (MOSTI) to support R&D in universities, with preference given to applications that show links with firms. Despite massive government focus, empirical evidence showed that few university–government relationships were established in automotive and electronics firms (Rasiah and Govindaraju 2009).

Thailand

The Thai university and research system is relatively young. The first university, Chulalongkorn University, was established in 1917, fol-

lowed by other universities in Bangkok focusing on public adminis-
tration, medicine, and agriculture. To counteract the polarization of
economic activities in the capital, regional universities were set up in the
North, Northeast, and South in the 1960s. A first academic diversifica-
tion toward technical colleges appeared in the 1970s when accelerated
industrialization led to a first labour shortage in science and technol-
ogy (S&T) (MUA 2002). In combination with a shortage of graduates
in S&T, there was a need to improve the quality and quantity of Thai
higher education (Chalamwong and Pomlakthong 2004). Four major
national research institutes were founded under the roof of the National
Science and Technology Development Agency (NSTDA), which is the
main agency to support S&T in the country: the National Center for
Genetic Engineering and Biotechnology (BIOTEC) established in 1983;
the National Metal and Materials Technology Center (MTEC) and the
National Electronics and Computer Technology Center (NECTEC) both
founded in 1986; and the National Nanotechnology Center (NANOTEC)
established in 2003. Since the opening of the Thailand Science Park in
2002 in the north of Bangkok, these national research centres have con-
centrated at this site. However, the impact of these institutions comes by
no means close to the role that similar institutions have played in Korea
and Taiwan. They remained rather distant from industry and focused on
technology-push. Government policies toward S&T rank rather low on
the political agenda, processes are highly centralized, and there is a redun-
dancy of organizations and programmes with similar objectives. This
leads to a fragmented and inefficient support system (Arnold et al. 2000).

The unsatisfactory performance of Thai higher education in the past,
and recent pressures on competitiveness, good governance, and fiscal
discipline, have led to a series of funding reforms and changes in the
science system. The most apparent feature is the stagnation of government
expenditure for higher education. Its relevance on the political agenda is
stagnant compared with other expenditure measures and does not match
the growth of the modern industrial sector (Suwanwela 2002, p. 21). The
National Education Act of 1999 permits universities to generate their
own income from endowments and assets, but with the exception of
Chulalongkorn University's land property in downtown Bangkok there is
no significant potential for these activities yet (Schiller and Liefner 2007).

Research could be a strategy to develop a unique academic profile and
to improve academic quality and funding (e.g., from research agencies).
Because it has to be based on a long-term vision and excellent research-
ers, very few Thai universities will be able to succeed. In S&T, research
activities started only 10–15 years ago on a regular basis. Public basic
funding does not cover research expenditure, and research agencies only

pay for current expenditure, not for investments in equipment. Therefore, only 20% of Thai academics conduct research continuously (Weesakul et al. 2004, p. 44). Academic services – the official third mission of Thai universities – promise additional funding and inputs to adjust research and teaching to market needs. In the past, links between Thai universities and the private sector have been based merely on informal consultancy services. The main aim of professors has been to obtain an additional personal income to augment the low salaries in the public sector (Schiller and Liefner 2007). The effect on their university work has been negative or at least indifferent due to their spending time outside university (Kirtikara 2002, p. 10). Nevertheless, Weesakul et al. (2004, p. 32) estimate the potential income from academic services for Thai public universities at THB2 billion (THB1 = USD0.03) or 15% of the total university budget if research commercialization were consistently promoted.

China

In the mid-1980s, the Chinese government shifted the focus of its reform and open door policy from the agricultural sector to the industrial sector and to science, technology, and education. In March 1985, the Central Committee of the Communist Party promulgated the Resolution on the Reform of the Science and Technology System, which states that economic development must rely on S&T, and that S&T research must turn to economic construction. Moreover, as a practical measure of the resolution, the Chinese central government started to cut down grants for academic institutions.

Under the strong influence of this resolution, Chinese universities were encouraged to engage in "socialist economic construction." The financial difficulties caused by the grant cuts pressured universities to find alternative sources of funds to survive, and also to think of setting up their own enterprises, i.e., university-run enterprises (UREs). Since the mid-1980s, "academic entrepreneurship" in Chinese universities has been supported by "social contracts" and has highlighted the willingness of individual universities to engage in economic activities.

Another condition for the emergence and growth of the UREs is the existence of "strong internal resources" in universities. These resources in Chinese universities originated from: (1) an application- and development-oriented research tradition; and (2) property rights and social capital nourished in the universities.

Chinese universities have mainly focused on applied research and development rather than basic research. The proportion of applied research expenditure (compared with the total research expenditure) in Chinese

universities has been about 60% throughout the 1990s. This down-stream tendency of Chinese universities originated from the characteristic Chinese distribution of functional activities – or division of labour across different institutions such as universities, academic research institutes, and industrial firms. Under the planned regime, the Chinese firms took up only a single function on the value-added chain, which is manufacturing, and some other social security functions (e.g., housing, medical service, and education), which are outside the value-added chain. The Chinese firms lacked functions like strategy, R&D, and marketing that have been taken for granted as major functions of a firm, especially in capitalist countries. In this sense, they resembled "branch plants" rather than corporations that are responsible for their own destiny in an uncertain market environ-ment. Furthermore, for such firms that are narrowly specialized (at least viewed from the standpoint of the value-added chain), the Chinese aca-demic institutions often had to produce actual "prototypes" or "samples" of the final products that the firms were supposed to reproduce on a larger scale. Through the practice of those downstream activities, the Chinese universities were able to accumulate experiences and know-how related to actual production, which generated valuable internal resources in setting up UREs.

In discussing the internal resources of Chinese universities, one should also consider the social or cultural factor. Every urban organization in China is based on the danwei system or "Chinese socialist work unit." The danwei is a self-sufficient and multifunctional social community that provides a basis for integrating those within it into an effective social, economic, and political unit. Chinese universities as danweis have been able to exercise "de facto property rights" (including intellectual property right) over the assets in the universities, although these property rights, in principle, belong to the "nation" or the "Chinese people." Chinese uni-versities have enjoyed an IPR regime that is similar to that of the US after the Bayh–Dole Act of 1980. Chinese universities have been able to com-mercially exploit the intellectual properties generated from their research projects funded by the central government. Although the Chinese version of the Bayh–Dole Act was officially promulgated as late as 2002, there has long been a post-Bayh–Dole regime (even before the Chinese patent law legislated in 1985) (Eun et al. 2006).

India

The foundation of India's NSI was perhaps laid by the Science Policy Resolution (GOI 1958). It was noted that India's enormous human resources become an asset in the modern world only when trained and

educated. This resulted in substantial investment in establishment of an elaborate system of education conducive to addressing not only the issue of widespread illiteracy but also the growing demand for highly skilled human resources for a growing economy (Joseph and Abraham 2011). The current higher education system is primarily modelled after the British system. However, some of the technical institutions in engineering and management are modelled after the US system. The higher education system remains primarily the responsibility of the state governments, although the central government has taken the initiative to establish and fund 20 central universities and other institutions of national reputation like the Indian Institutes of Technology (Chakrabarti 2007). The dynamic role of the interface between universities and industry in strengthening national technological capability and international competitiveness is increasingly being recognized. The New Economic Policies launched in 1991 are driving universities toward industry and vice versa. With the ongoing economic reforms, there has been a drastic change in the economic environment for firms, academia, and public laboratories: liberalization efforts are removing controls and protection is replaced by competition; export promotion is substituted for import substitution; and state support is more and more withdrawn from higher education and research. These policies are pushing the academic system toward commercialization to ensure financing for research and even teaching activities. Due to the liberalization of the economy, the industrial sector feels the pressure to upgrade technologically to stay competitive in the home market and globally. Technology purchased from transnational corporations is insufficient for this endeavour because those corporations are the competitors in both markets. Thus, the industrial sector is more frequently relying on academia as a new source of knowledge (Joseph and Abraham 2009).

EMPIRICAL EVIDENCE OF UILs IN FIVE ASIAN COUNTRIES

Macro-institutional Arrangements

The surveys in five Asian countries suggest that UILs are not widely spread. Most of the countries are still at an early stage of the catch-up process, and there are only a few successful cases of firms and PROs that have reached medium levels. In terms of R&D intensity in the manufacturing sector, Malaysia and China seem to be more advanced than Thailand and India. However, India has particular strengths in the service sector,

whereas R&D and innovation activities in Thailand remain shallow in general. Korea is the most exceptional among the five countries. Many of its large firms and some universities have reached the mature stage of technological and academic capabilities. However, even in the case of Korea, UILs are relatively new and are still not widely spread.

In Korea, the legacy of the catch-up innovation regime is still clearly visible and might be a barrier for more intense UILs. The innovation system was dominated by large firms and direct government interventions (Eom and Lee 2010). Knowledge transfer took place by tapping into global knowledge sources via technology transfer and hiring of foreign experts. SMEs and local universities did not play an active role in innovation and upgrading processes, whereas Chaebols and some large GRIs were relatively dominant. Nevertheless, Korean PROs reached advanced levels in terms of academic capabilities. Only since the very late 1990s or 2000s, have policies to promote horizontal links between science and industry been introduced. Since then, UILs have increased in importance: more than half of the professors reported active collaboration; and among firms the share of collaborators was on the rise, although still at a low level. Besides the role of public policy for the promotion of UILs, there seems to be evidence of a positive link between the level of economic development of a nation or capability of a firm and the extent of UILs.

In the other countries, similar developments have been observed, although at a lower level in general. Malaysia and India had already introduced policies to stimulate UILs in the 1990s, and China had a tradition of transferring scientific knowledge via UREs since the reform and opening policy was introduced (Eun et al. 2006). The spreading of UILs remains lowest in India and Thailand. A very low number of firms reported any active involvement in UILs, and PROs were assessed as the least important external knowledge source. Thailand also seems to be the only country without any proactive policies to promote UILs on a larger scale, which is in line with the passivity of the country's policies in the field of S&T in general. China and Malaysia reported links with the science system at a level that is at least comparable to other horizontal forms of knowledge transfer.

Remarkable differences are observed with regard to the relative importance of different actors in forming UILs. With the exception of India, universities are the most important partners for firms in most countries. This finding is particularly surprising in cases like Korea or China, which have a long tradition of predominantly allocating research functions in GRIs. Despite their superior research capabilities in the past, these actors were not able to transform themselves into relevant partners for private firms at a time when horizontal links became more important within the

innovation system. Research at universities was promoted, and they seized the opportunity to move closer to private-sector needs more quickly. A major reason for this fact might be the institutional legacy of GRIs in top-down innovation systems that hindered rapid transition.

This discussion indicates the very dynamic and country-specific nature of the UILs in the five Asian countries – it depends on diverse factors that are constantly changing. This means that any study that aims to derive policy suggestions must keep this in mind and should not take up any static or overly abstract view on the UILs in developing or latecomer countries. Although we can and should put the UILs in the broader evolutionary and institutional perspective of the innovation system, the innovation system itself should be understood as constantly evolving and reflecting the local specificities of each country and its policy initiatives.

Modes of Collaboration

The surveys in Asian countries found that, in general, formal channels and closed forms of collaboration are more common than informal arrangements and open innovation. Contract-based research is most common in Korea. In Malaysia, the common modes include teaching-based UILs and services like testing and quality control. Small-scale consulting services are most common in Thailand and India. These patterns differ markedly from findings from the US (Carnegie Mellon Survey) by Cohen et al. (2002) and Branscomb et al. (1999), which propose that open science channels, like conferences and papers, as well as informal interactions, are more common. These findings can be interpreted to be consistent with the hypothesis that different modes correspond to the different stages of economic development of nations and the different capabilities of firms in each country.

China is a unique case because its UILs were dominated by commercialization via UREs, i.e., enterprises were established and run (unlike spin-offs) by the universities themselves. Major factors that led to the growth of UREs in China were: the pressure on PROs to become financially independent as the whole economy became more market oriented; institutional deficiencies that hindered a trustworthy protection of IPR; and a lack of private-sector partners with sufficient absorptive capacities. In recent years, absorptive capacities have quickly risen among domestic firms, and the institutional framework was improved at least to some degree. As a result, vertical commercialization via UREs is gradually substituted by horizontal modes of UILs (Eun and Lee 2010). Indian universities and public laboratories neither set up their own companies nor tried to sell or license technologies to a larger degree, despite the relatively

strong research capabilities of universities or public laboratories at some outstanding organizations like the Indian Institutes of Technology. This pattern also seems to be related to a social tradition of academic institutions that does not attach much value to such activities. The case of low capabilities of both firms and universities may apply to Thailand and Malaysia, where most university and industry interaction takes the form of consultancy services by the universities.

The scope of most UIL projects is clearly limited to short-term problem solving. If a particular problem occurs in a firm, an acquainted partner at the university might be hired for the solution. In more advanced cases, it will be a project that involves proper research, as in the case of Korea. In less advanced cases, the researcher will be hired as a short-term consultant, as in the case of Thailand and China. Due to the relatively high level of research capabilities at Korean universities compared to the other four countries, only in Korea are research-based UILs formed in a larger number of cases. In Thailand and India, some university departments have specialized in offering their equipment to firms for testing of samples and quality control. Although this activity might yield some economic benefit, its learning potentials are obviously limited and it raises the question of whether publicly subsidized equipment should be used to crowd out private sector activities when establishing an infrastructure of test laboratories and certification bodies (see Tables 2.2, 2.3, and 2.4 for an overview of UIL modes in Korea, China, and Thailand).

Teaching-based UILs are certainly an outstanding and very promising mode of interaction among science and industry. They have a large potential to contribute to catch-up processes in Asian latecomer countries due to the teaching tradition of the universities and the need for human capital with relevant skills. Malaysia and Thailand reported particularly high levels of participation of firms in curriculum development, formalized internship programmes, and specific training of students according to industry needs. Some importance of these modes was observed in China and India. However, this was not the case in Korea, where the education system might be advanced enough to produce the large number of adequately qualified graduates for the needs of industry. Access to well-trained graduates has proven to be a very strong incentive that universities can offer to firms as a reward for closer interaction. In this case, the direction of knowledge transfer may even be reversed, and universities will learn from firms.

Firms are in most cases collaborating with universities to passively apply ready-made scientific artefacts in their production processes. Either existing university equipment, which is not available in the respective firm, is accessed, or existing knowledge is tapped into by hiring researchers as

Table 2.2   Modes of UILs in Korea

Modes	From or with universities		From or with GRIs	
	Number	%	Number	%
Contract (collaborate or separate) research	242	62.9	192	58
Patents licensing and technical learning	11	2.9	16	4.8
Mutual use of R&D facilities and equipment	62	16.1	75	22.7
Mutual dispatch of researchers and students and doing collaborative research	13	3.4	4	1.2
Creating joint venture or spin-off under the technological collaboration with PROs	1	0.3	9	2.7
Dispatching corporate researchers to universities or GRIs and technical learning	8	2.1	0	0
Technical consulting and special lectures of professors from universities or researchers from GRIs	34	8.8	27	8.2
Designating professors or researchers as formal advisory member and taking advices from them	14	3.6	8	2.4
Total	385	100	331	100

Note: Minor deviations from 100% can occur due to rounding differences.

Source: Lee et al. (2009).

consultants. Joint knowledge creation and its proactive application in R&D activities is only relevant to any greater extent in Korea. Thereby, the effect of the majority of UILs on absorptive capacities and innovation potentials remains limited.

The motivation of PROs to enter UILs is mostly driven by economic pressure rather than intellectual endeavour. Korea is the only case with a higher importance of intellectual gains. Thailand and India are the countries that experienced the most serious funding pressures due to a reduction of government spending for higher education. It is important

Table 2.3   Modes of UILs in China

Channel that contributes to innovation in the firm	Moderately or very important	%	Very important	%
Joint or cooperative R&D projects	193 (1st)	63.9	105 (2nd)	34.8
Licensed technology	178 (2nd)	58.9	78 (3rd)	25.8
Patents	174 (3rd)	57.6	107 (1st)	35.4
Recently hired graduates with above-Master degree	159	52.6	74	24.5
Consulting with individual researchers	159	52.6	62	20.5
Contracting research	159	52.6	70	23.2
Science or technology parks	141	46.7	61	20.2
Publication and reports	130	43.0	44	14.6
Temporary personnel exchanges	120	39.7	34 (−3rd)	11.3
Informal information exchange	118	39.1	35	11.6
Public conferences and meetings	110 (−3rd)	36.4	24 (−1st)	7.9
Incubators	109 (−2nd)	36.1	42	13.9
Participation in networks that involve universities	96 (−1st)	31.8	31 (−2nd)	10.3

Source: Eun et al. (2009).

to mention that an early reduction of higher education funding in Asian latecomer countries is in conflict with the overall aim of economic and technological catch up. If PROs are to become relevant knowledge sources at later stages of the catch-up process, sufficient public funding is required to build advanced academic capabilities that enable the science sector to provide adequately trained graduates and research-based UILs. Otherwise, the respective science systems are at risk of becoming occupied by the opportunistic behaviour of its members, and by collaborating firms that try to reap short-term individual profits from publicly endowed equipment without contributing to the enhancement of the science system in the long run. Only science systems with an academically strong core will be able to become entrepreneurial in a way that benefits the catch-up process and society as a whole.

Table 2.4   Modes of UILs in Thailand (n = 136, multiple answers possible)

Mode of interaction	Share of professors using this mode	Mode of interaction (continued)	Share of professors using this mode
Consulting services	49%	Joint research project	7%
Technical services	35%	Staff mobility	4%
Informal meetings	20%	Joint labs at company	4%
Licensing	17%	Joint patents	3%
Contract research consulting	15%	Spin-offs (planned)	3%
Joint conferences	8%	Demonstration of research	2%
Training of industry staff	8%	Joint publication	1%
Sale of products	8%	R&D consortia	1%
Internships	7%	Joint laboratories at university	1%

Source: Schiller (2006).

Outcomes and Benefits of UILs

The question about outcomes from UILs is related to the interplay of R&D by firms and by universities, namely, the question of whether they are substituting or complementing each other. The survey results seem to suggest that their relationship is complementary in most cases, i.e., UILs are formed after firms started their own R&D or innovation activities. The complementary character is proven by the fact that firms with R&D activities have a higher propensity to collaborate with PROs. However, this does not mean that there is no substituting aspect. The common modes of contract research and consulting imply some degree of substitution because firms seem to rely on existing competences in the science system instead of developing them in house. But complementary capabilities are nevertheless necessary to implement the results received from such linear modes of collaboration. Only the use of testing and quality-control services is clearly a substitutive mode of UILs. To summarize, just relying on outside help for the R&D problems of firms does not seem to guarantee success in business projects unless this is combined with strong and planned effort from the firm's side. The reality might exist somewhere between these two extremes of substitutes and complements.

The question of whether the industrial partner or the scientific partner gains more knowledge from UILs is maybe even more relevant than the discussion about complements and substitutes. The theory assumes that, in general, both partners of an interactive learning process will augment their knowledge base by sharing knowledge. Nevertheless, the net knowledge gain is implicitly expected to be larger for firms that gain scientific knowledge that is valuable for their R&D and innovation output. However, there is evidence from empirical research in Asian latecomer countries that firms with active involvement in R&D, particularly some advanced domestic firms and foreign firms with an innovative home base, possess superior technological capabilities compared to the academic ones of universities. Especially in the case of Thailand and for most teaching-based UILs, the university partner benefits from the collaboration not only economically, but by accessing state-of-the-art technologies and equipment in an applied research field. Therefore, UILs also have an often overlooked potential to upgrade the academic capabilities of universities, which may have a widespread effect on the role of the science system for maturing the catch-up process in the long run. As with other indicators, the net knowledge gain shifts toward the industrial partners at later stages of the catch up, as in the case of Korea.

A promising finding from the surveys is that firms that collaborate with PROs tend to be satisfied with the interaction (Tables 2.5 and 2.6). In Korea, more than 63% of the surveyed firms answered that they were satisfied with or optimistic about the outcome of their interaction with PROs. Malaysia and India report similar satisfaction rates, which shows

Table 2.5   Performance of the UILs in Korea

Success or failure of performance	Universities		GRIs	
	Number	%	Number	%
So far, it is successful	121	31.5	111	33.9
The collaboration is going on and it will be successful soon or later	118	30.7	88	26.9
The collaboration is going on but it will not be successful	45	11.7	33	10.1
So far, it is not successful	100	26	95	29.1
Total	384	100	327	100

Note: Minor deviations from 100% can occur due to rounding differences.

Source: Lee et al. (2009).

Table 2.6   Success rates of collaboration in Malaysia

Success or failure of performance	Automotives		Biotechnology		Electronics	
	Number	%	Number	%	Number	%
Yes	15	23	101	86	73	61
No	41	62	4	3	18	15
Expect it to be successful	10	15	10	9	23	19
Do not expect it to be successful	0	0	2	2	5	4

Source: Rasiah and Govindaraju (2009) in Lee et al. (2009).

that firms may conclude follow-up collaboration and that trust-based long-term relationships may be formed. However, the high satisfaction rates in India and Malaysia could also be an indication of a less demanding attitude of firms and limited ability to critically assess the quality of the project outcome. Korean firms, although seeing their expectation satisfied, admit that 40% of the projects are failures. This rate of failure is an almost natural result of more sophisticated UILs with the involvement of more risky in-depth research. However, such failures that are rooted in the nature of real innovation processes must be understood by both partners, and they are only guaranteed if cognitive proximity is sufficiently high and a trust-based relationship exists.

The high satisfaction rate could be tentatively taken as evidence for the effectiveness of UILs in terms of performance enhancement. However, some caution is necessary because of a problem of endogeneity, i.e., firms already actively involved in R&D tend to collaborate with universities. In other words, there is a potential issue of "self-selection." Such reasoning is supported by an econometric study on the impact of UILs on firm performance in Korea by Eom and Lee (2010). Their findings suggest that collaboration with PROs fails to significantly increase the innovation success of firms when controlling for the endogeneity of the collaboration, whereas the positive effects of collaboration on the innovation probability are only found in a regression that does not control for endogeneity. The results imply that capable firms tend to collaborate with universities, instead of becoming capable by collaborating.

When we limit our analysis to those firms succeeding in innovation, we find that collaboration with universities tends to lead to product innovation rather than process innovation, as suggested by the survey in India and by the analysis of Eom and Lee (2010). This finding is consistent with observations in the literature (George et al. 2002; Mowery and Sampat

2005) that, owing to the characteristics of knowledge in the science system or way of knowledge transfer, UILs may not directly influence firm success in innovation. Rather, it can affect the decision making or management of research projects in firms. In the other Asian countries, impacts on learning and long-term innovativeness also seem to be limited. If measurable impacts are identified at all, they are limited to short-term problem solving rather than long-term involvement in upgrading and innovation.

The finding that UILs tend to lead more from product innovation than process innovation should be taken cautiously. The type and nature of outcome from collaboration with universities should depend on the modes of collaboration. If the cooperation aims at technical consultation, it is more likely to lead to process or minor innovation. If the mode is contracted research targeting more radical R&D products, this might result in more product innovation. This argument is in line with observations from Korea that are noted in several studies (Park et al. 2000; SERI 2006). In the past, PROs may have contributed more to process innovation because firms themselves are preoccupied with reverse engineering, problem solving, and minor innovations. However, at present, the level of technological capabilities among Korean firms has improved to a certain extent, and they feel more need for R&D collaboration to generate product innovation. This result also seems to reflect to a certain degree the fact that the outcomes of process innovation tend to be less readily protected via patents. Rather, they are often exploited internally, or they constitute a part of product innovation (Rouvinen 2002). Thus, our position is not to say that successful UILs do not take the form of process innovation, but only that they tend to show up more in product innovation and related patents.

One of the most common answers of firms about the barriers to collaborate with PROs was that the R&D activities of firms and scientific partners were too weak to conduct meaningful R&D, not to mention collaborative R&D. For example, more than 30% of the Korean firms self-critically identified a lack of interest or capability of firms as the main reason for the lack of UILs (see Tables 2.7 and 2.8 for an overview of barriers in Korea and China from the firm perspective, and Table 2.9 for the university perspective in Thailand). This answer seems to reflect the problem with absorptive capacities of firms. As noted in the work of Eun et al. (2006), universities in China ended up establishing their own start-up companies because they found existing firms to be less capable of absorbing innovation outcomes from universities. However, a recent survey of UREs across China found that this source of knowledge transfer is diminishing (Eun and Lee 2010).

Another common answer regarding weak collaboration was the

Table 2.7   Barriers to UILs in Korea (firm survey)

Possible reasons for lack of links	Before 2000		After 2000	
	Number	%	Number	%
Lack of interest or capability of professors and universities	24	6.2	26	7.5
Lack of interest or capability of firms	127	32.8	116	33.6
Lack of support policy and institution of the government	30	7.8	33	9.6
Lack of collaborative infrastructure between firms and universities	176	45.5	132	38.3
Others	1	0.3	3	0.9
No necessity	24	6.2	28	8.1
No idea or no responses	5	1.3	7	2
Total	387	100	345	100

Note: Minor deviations from 100% can occur due to rounding differences.

Source: Lee et al. (2009).

Table 2.8   Barriers to UILs in China (firm survey)

Possible reasons for lack of links	Number	%	Category
The firm's R&D is enough to innovate (*n* = 74)	25	33.8	Firm-specific
GRIs have no understanding of our line of business (*n* = 73)	24	32.9	Cultural
Universities have no understanding of our line of business (*n* = 73)	24	32.9	Cultural
Intellectual property issue (*n* = 73)	18	24.7	Transaction cost
Contractual agreements are difficult (*n* = 73)	18	24.7	Transaction cost
Universities and GRIs concerned only with big science (*n* = 73)	16	21.9	Cultural
Lack of trust (*n* = 73)	13	17.8	Transaction cost
Quality of research is low (*n* = 73)	12	16.4	Other
Difficulties in dialogue (*n* = 73)	7	9.6	Cultural
Geographic distance (*n* = 73)	6	8.2	Other

Source: Eun et al. (2009).

Table 2.9   Barriers to UILs in Thailand (university survey)

Possible reasons for lack of links	Very important (%)	Important (%)	Less important (%)	Unimportant (%)
Industry does not want to cooperate	45.0	15.0	21.7	18.3
Industrial partners are not available	16.7	18.3	25.0	40.0
Bureaucratic restrictions	13.1	21.3	26.2	39.3
Other duties, no time	9.8	24.6	32.8	32.8
Missing support for finding partners	11.5	16.4	39.3	32.8
Fear of losing knowledge	11.7	15.0	23.3	50.0
Lack of incentive schemes	6.7	20.0	26.7	46.7
No extra funding for cooperation	1.6	13.1	18.0	67.2
No influence on academic reputation	1.7	10.0	25.0	63.3
Uninteresting outcomes	3.3	8.2	18.0	70.5
Freedom of research rules it out	6.6	1.6	14.8	77.0

Source: Schiller (2006).

mismatch or lack of understanding (trust) on both sides, which results in each side perceiving a lack of understanding of their own situation or problem on the other side. For example, more than 60% of the firms answered that PROs do not have any understanding of their line of business. This generally should be the result of a mismatch in capabilities and area of expertise or knowledge. To a certain extent, such a mismatch is also related to the weak infrastructure supporting the collaboration between the two parties, such as property right regimes, physical facilities, incentives schemes, and technology markets. The importance of formalized UILs in all countries, and the prevalence of interactions that were sometimes even designed by public policy, for example in India, are an indirect proof of: a low level of trust among science and industry in general; a lack of individual experience in jointly carrying out collaborative innovation projects; and the low level of real research being performed in the majority of UILs. Successful processes of interactive learning require open-ended and trust-based forms of working together. The learning outcomes of overtly linear forms of knowledge transfer among actors with low absorptive capacities will remain shallow.

Regional and Sectoral Differences

Firm characteristics were found to have an impact on UILs in all countries. However, the survey results do not confirm the hypothesis that SMEs with fewer in-house resources for R&D and innovation are more externally oriented and thus more intensely involved in UILs. We actually found that firms that have certain R&D capabilities and thus do some in-house R&D are the most frequent users of services from PROs. Relatively large-size firms tend to be more active in collaboration with universities. The positive effect of firm size seems to be more pronounced in countries with a lower level of general economic development. It seems to be lowest for Korea and Malaysia, the latter of which is the second most economically developed country in the sample. Medium-size firms that had reached a critical mass of resources for carrying out R&D, but were not too big and inward looking, were particularly important. Furthermore, domestic firms in Thailand and state-owned enterprises in China collaborate more intensely with universities. But neither size nor ownership seems to be the decisive factor that explains UIL intensity. Both are mediated by whether or not the firm performs R&D activities at its present location. Among domestic firms, R&D performers are mostly larger firms that have the necessary resources in terms of human and financial capital to get involved in risky long-term operations, whereas most SMEs in Asian latecomer countries struggle to manage basic production capabilities. Subsidiaries of foreign firms are often not performing R&D activities in their host countries, but tend to rely on the R&D done by their parent companies abroad. However, there are some remarkable cases of foreign firms, for example multinational hard-drive manufacturers in Thailand, who collaborate intensely with universities in catch-up countries to improve the quality of study programmes and the skills of potential employees for their firms.

As far as sufficient evidence on sectoral differentiations is available from the surveys, there is some support for the proposition that UILs are not necessarily most intense in high-tech sectors. Especially in the cases of Thailand's food, textile, rubber and plastic, and petroleum industries, and to a smaller degree in Malaysia's agricultural-related biotechnology, relatively more UILs are found in low- and medium-technology fields. The cognitive proximity between science and industry is arguably higher in these fields than in high-tech fields that are often dominated by foreign firms. There is less demand for local UILs based on basic research, which is less prominent in science systems of Asian latecomer countries compared to applied research. Korea is also an exception in this case with its pronounced high-tech focus of UILs. More advanced research-based UILs are more often found in high-tech sectors, whereas low-level

collaborations like informal meetings, consulting, and teaching-based UILs are found relatively often in Korean low-tech sectors like the food and textile industries. These low-tech UILs may be interpreted as relicts from early catch-up stages when these sectors dominated the Korean industry and served as a starting point for initial interactions between science and industry. Other sectoral peculiarities that are documented in the UIL literature in general are also observed in the Asian countries. The automobile industry has less collaboration with the science sector due to its focus on engineering innovation rather than scientific knowledge bases, whereas biotechnology is much more science based and thus has a stronger propensity to form UILs.

Regional aspects have been covered in the studies on Thailand, China, and India. In Thailand and India, the hypothesis about the predominance of UILs in the economic centres is confirmed. UILs in India differ largely among the seven regions covered by the survey. The strongest collaboration was found in the longest-established industrial area of Mumbai, and had a focus on megacities in general instead of peripheral locations. Regions like Pune that are dominated by foreign firms and the automobile industry, which less frequently collaborates with universities, also have fewer UILs. In Thailand, most UILs are formed between partners in Bangkok and its vicinity (Schiller 2006). Although some of the strong research universities are located in peripheral regions, these universities have difficulties finding industrial partners in geographic proximity. They either collaborate with firms in Bangkok and abroad or offer outreach services to local communities with a focus on agricultural-related issues.

Regional UIL patterns in China differ from the observations in Thailand and India. Firms in the Midwest collaborate more intensely than firms along the East Coast. This might be due to the fact that firms in the economic core regions have access to other (international) knowledge sources. Because state-owned firms have easier access to the public universities than private firms, the dominance of private domestic and foreign firms may also contribute to this pattern. In contrast, state-owned firms dominate in the peripheral areas and may thus generate the higher UIL intensity in these regions. UILs in China are concentrated among a limited number of national key universities, which have been promoted by the Ministry of Education within the so-called Project 211 since 1995. These universities are also collaborating with firms in other provinces. Interestingly, some private Chinese firms are more often getting in contact with foreign universities than with local universities that are less accessible to them. Because many private entrepreneurs of innovative firms are returnees who studied or even worked abroad, they might have established contacts to these foreign universities already.

Comparison with Latin America

The comparison of the Asian results with those from four Latin American countries (Argentina, Brazil, Mexico, and Costa Rica) shows several similarities, but also some interesting differences. The comparative results for Latin American countries are discussed in detail by Dutrénit and Arza (2010). Latin American countries realized a lower level of economic performance and speed of catch up. There were at least two decades of stagnation during the 1980s and 1990s and overwhelming structural problems, such as social inequalities and poor education, but the institutional setting for PROs is nevertheless quite similar.

Universities still have a teaching focus although they have a higher basis in scientific research than in Asia; GRIs are closely connected to the research agendas of the respective governments; and funding pressures are even more severe in many countries due to the state of public finances. But universities have played a more important political role in Latin American than in Asia, and many universities were rather opposed to the government and, in particular, to the private sector during the period of authoritarian regimes. Nevertheless, UILs seem to be somewhat more widespread in the four Latin American countries, particularly in indigenous firms, than in the Asian countries. A reason for this fact might be the lower integration of foreign firms within the value chains of small local firms compared to Asia. Therefore, there is a greater necessity to turn to local universities for knowledge inputs. In this respect, it is particularly interesting that UILs were critical for breakthroughs in certain national key sectors of each country (e.g., the agricultural technology in Argentina, the aircraft and steel industry in Brazil, and the chemical industry in Mexico). The level of sophistication of UIL modes is similar to Asia and mostly limited to small-scale services with short-term performance effects for firms and without a lot of intellectual benefits for researchers. Academic services (e.g., consulting, testing, and informal exchange) and traditional modes of exchange (e.g., conferences, publications, and hiring of graduates) prevail, whereas bi-directional collaboration (e.g., contract research and joint research) are more beneficial for the partners, but are less often applied due to capability lacks or gaps. Commercialization modes (patents, licences, spin-offs) are the least important mode despite their prominence on the innovation-policy agenda.

UILs in Latin America seem to be less formalized than in most Asian countries, which might be a result of their longer history and the resulting trust among science and industry. For the interpretation of the comparative results, it has to be kept in mind that the focus of the Asian surveys was particularly on collaboration between PROs and the manufacturing

sector, whereas the Latin American and African studies also covered other sectors of the economy. This might be another reason for the lower formalization – technological innovations in manufacturing are supposed to be more formal on average than consulting projects in the service sector.

SYNTHESIS AND CONCLUDING REMARKS: UILs AS A VEHICLE FOR CATCH UP

Early Starts for Long-term and Sustained Catch Up

The analysis of the survey results from five Asian countries has shown clearly that one should not expect UILs to have a very high and statistically measurable impact at early stages of the catch-up process. At that stage, the academic capabilities of most PROs and the technological capabilities of most firms are still low, and absorptive capacities and collaboration potential among the two sectors are shallow. Firms tend to rely on foreign knowledge sources in the form of licensing and reverse engineering or on collaboration with customers and parent companies. This collaboration can undoubtedly serve as a window of learning and capacity building, as was the case of Korea in the past. However, the opening of channels for UILs as early as possible is necessary to keep up the pace of the catch-up process beyond intermediate stages and toward maturation. The experience of first-generation catch-up countries like Korea has shown that their innovation systems will reach a stage of economic and technological development at which the reliance on foreign knowledge transfer becomes insufficient to close the gap to leading firms and countries. Vertical knowledge transfer, imitative learning, and the reliance on large firms have to be complemented by horizontal links, creative learning, and indigenous knowledge sources. UILs with local PROs are the critical vehicle to nurture this transition.

Arguably, Korea stands out as a case of successful catch up, but it also serves as an example of a country that started to promote UILs relatively late compared to its economic success. The transition toward a horizontal innovation system was introduced rather late; therefore, the country had to realize underlying structural weaknesses in a highly visible way during the aftermath of the Asian crisis in 1997. The institutional legacies of the early catch-up regime are still visible in the data on UILs, and they do not invigorate R&D and innovation activities in a systematic way.

Because horizontal links tend to become important for the innovation system at later stages of the catch-up process, the promotion of UILs at

an early stage allows for the evolution of time-tested interfaces and trust building among science and industry and, thus, keeps catch-up innovation systems prepared for future challenges. Therefore, low-threshold UILs at early stages may pay off in the long run if they help to build trust between partners and if they are allowed to grow in a bottom-up and evolutionary way rather than if collaboration is planned in a top-down and disruptive manner.

From Dichotomy to Absorptive Capacity

The fact that firms that already perform R&D activities tend to collaborate more with PROs might indicate the limitation of UILs as a new vehicle for catch up. Although we assign more weight to the supplementary role of UILs than their substituting role, this does not mean that PROs cannot be of help to those firms with weak R&D capabilities. As long as firms have a strong will to solve their problems and actively seek both inside and outside help, PROs can and will be sources of solutions. The positive evaluation of the firm's experiences with collaboration is consistent with such reasoning.

Beyond the dichotomized question of the complementing or substituting role of UILs, what matters more seems to be the absorptive capacity of the firms and the various academic capabilities (teaching, research, and entrepreneurial) of PROs. If such capabilities are provided, there is no doubt that UILs will become more intense. Right now, the extent of UILs tends to be low although increasing in most latecomer countries. Given the low extent and scattered availability of capabilities of firms and universities in latecomer economies, it is important to increase the level of their capabilities first, and later to use diverse modes of UILs that depend on specific conditions and contexts.

Effective Modes of UILs

Some modes of UILs seem to be better suited to serve as starting points for the opening of interfaces between science and industry. Teaching-based UILs are a mutually beneficial way to start interactions. They have the potential both to help firms with low absorptive capacities by providing exclusive access to highly qualified students, and to help universities with low academic capabilities make their curricula more relevant to industry needs and state-of-the-art technologies. Closed forms of collaboration (e.g., consulting and contract research) that are focused on solving clearly specified problems are valuable to reap first successes from UILs, which can be deepened in the future.

The focus should be on projects that can be managed, and whose results can be implemented by the collaborating partners given their yet limited capabilities. If the degree of sophistication is too high, as is often the case for publicly designed and promoted UILs, the risk of failure and loss of trust is very high while the potential of valuable outcomes remains rather low. In addition, individual actors and personalized capabilities are expected to be of particular importance for the conclusion of meaningful UILs because general institutional trust does not exist among science and industry yet and advanced capabilities are not yet widely spread among actors in science and industry. These outstanding individuals include researchers and administrators at universities, entrepreneurs of SMEs, and managers and top engineers in large firms. They have to be provided with the necessary institutional and financial resources to demonstrate the mutual benefits of UILs to others.

It is in general not recommended to stick to one single mode of UILs, but, for example, to combine teaching-based UILs with research-based projects. For this reason, it is important to identify successful examples of UILs and to diffuse them widely within the innovation system, to other regions within the country, and to other catch-up countries.

GRIs versus Universities

Interactions with firms should be sought by universities as well as GRIs, and a clear division of labour among both players of the science system should be implemented from early on. The survey provides evidence for the conclusion that GRIs with a big science focus and close links to the government, as in the case of Korea and China, had the most difficulties in transforming themselves into trusted partners for interactive learning and innovation with firms. Universities started later with introducing research functions, but overtook GRIs in terms of importance as a knowledge source in all countries besides India. It seems to be desirable to endow universities with a strong research function. Top universities, like the Chinese Project 211 universities, should become more basic science oriented, whereas other universities should keep their applied research focus. GRIs will be most likely successful in linking with industrial partners if they adopt an applied research orientation that is closely related to industry demand. The Fraunhofer Institutes in Germany could serve as a role model for the transformation of GRIs into research-based knowledge providers with high relevance for industry. Nevertheless, the borders of both kinds of organizations should be fluid to avoid the blocking of science–science links.

Key Guidelines for Public Policies in UILs

Public-policy interventions to promote UILs should focus on strengthening the academic core of the science system by providing public funds and improving the institutional framework for UILs. Top-down planning of UILs and the establishment of technology licensing offices with a focus on commercialization of existing inventions in a linear way are less promising. Notwithstanding the fact that such programmes are regularly used in Asian latecomer countries and try to resemble Anglo-American success stories, they often fail due to the negligence of important characteristics of learning and innovation (i.e., interactive nature, path dependence, and proximity among the partners; and the specific context of catch-up regimes). For example, the conception of the three major GRIs in Thailand (National Center for Genetic Engineering and Biotechnology [BIOTEC], National Electronics and Computer Technology Center [NECTEC], and National Metal and Materials Technology Center [MTEC]), which were founded with the support of United States Agency for International Development (USAID) in the 1980s, was and remains in large parts based on the technology-push paradigm. They were criticized for producing knowledge for companies, not in collaboration with them (Arnold et al. 2000). As a result, they are much less important as a collaboration partner for industry than universities (Intarakumnerd and Schiller 2009). Instead, the science system in Asian latecomer countries still needs basic investments to develop academic capabilities that have the characteristics of a public good. It is not expected that these investments will be provided by private actors via UILs. The tendency to reduce public funding for the science system as reported in the cases of Thailand (Schiller and Liefner 2007) and India (Joseph and Abraham 2011) seems to be very inappropriate to spur meaningful research-based UILs in particular and the catch-up process in general.

This discussion has shown the dynamic and context-specific nature of UILs in each country, and their dependency on several constantly changing institutional factors. This means that any policy suggestion should not take up any static or overly abstract view on UILs in Asian latecomer countries. Although we can interpret UILs against the broader framework of the NSI, this system itself should be understood as constantly evolving, and reflecting the local specificities of each country and its policy initiatives.

Future Research Agenda

There is not only need for better public policies to increase the role of UILs during the catch-up process. Scientists interested in the issue of economic

and technological catch up are also encouraged to conduct more research on UILs in latecomer countries to better understand their functioning. Based on our review of Asian examples, the following three topics seem to be of particular relevance for future research:

(1) Research on innovation systems and UILs was focused on the technological dimension for a long time. It would be worthwhile to conduct more studies that understand the governance mechanisms (e.g., institutional designs, funding, and incentives) at work within the science system and the levels of academic capabilities in addition to technological capabilities of firms.
(2) The low level of UILs in general makes it difficult to measure the impact of these interactions in a quantitative way by large-scale surveys. There is a lot of potential for in-depth case studies about successful and failed UILs in latecomer countries. The knowledge about these context-specific cases should be diffused across the whole innovation system to demonstrate how UILs could be initiated and which mistakes should be avoided.
(3) Innovation potentials in latecomer countries are often highly concentrated within particular regions (e.g., core regions) and among a limited number of actors (e.g., large firms) or sectors (e.g., traditional sectors with a high number of domestic firms). Future studies should address the issue of fragmentation and try to understand whether and how it affects the catch-up process.

3. Features of interactions between public research organizations and industry in Latin America: the perspective of researchers and firms

Gabriela Dutrénit and Valeria Arza

The National Systems of Innovation (NSIs) of Latin American countries have been shaped by a set of factors. First, institutional building emerged from the intertwining of old institutions generated during the import substitution period and new institutions that emerged after the liberalization process since the 1980s, which sometimes implies lack of consistency in policy guidelines. Second, persistent macro instability and dramatic crises episodes (in the 1980s, 1990s, and currently) affected the long-term behaviour and performance of firms in the region. Third, levels of poverty reflect social needs that have not been satisfied, and income inequality creates power asymmetries, which undermine the possibility of building durable consensus and divert the design of public policy from the needs of the majority.

Partly as a consequence of these factors, the NSIs of Latin American countries have not followed the path of learning societies (Arocena and Sutz 2000a): innovative capabilities are rather poor (e.g., low investment in private research and development [R&D]); the proportion of human resources in science and technology (S&T) is low; and there is a general perception that the interactions between universities and public research organizations (PROs),[1] and industry are weak (Cimoli 2000; Cassiolato et al. 2003; López 2007; Dutrénit et al. 2010a).[2]

PROs play a key role in upgrading the NSI because they create and disseminate knowledge. Not only do they train graduates and contribute to

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[1] We use PRO to refer to public institutions where knowledge is produced. PROs are similar to universities and research centres. In Latin America, many of the research institutes are public, and in some of these institutes, researchers receive a set of common incentives that contributes to explaining how they tend to interact.

[2] The same pattern is described by Lall and Pietrobelli (2002), Muchie et al. (2003), and Lorentzen (2009b) referring to African countries.

the stock of knowledge from which other agents can draw, they may make more direct contributions to the demands for knowledge from society. In this chapter we concentrate on PRO–industry (PRO–I) interactions, which may imply direct contributions of PROs to technological upgrading by firms and to new sources of inspiration and fields of application for PRO research activities.

Traditionally, Latin American universities have been quite disconnected from both government and industry. Consequently, their interactions with other agents have been poor. This pattern also applies largely to PROs. Because the innovative capabilities of firms and the knowledge skills of PROs are limited, interactions that have emerged since the 1990s have not contributed to the creation and diffusion of knowledge. This has not allowed the advantages of interaction to strengthen the innovative capabilities of firms or the knowledge skills of researchers. These particularities help explain the weakness observed in the NSI of Latin American countries when compared to other regions. However, there is plenty of evidence that PROs can make important contributions to increase the economic performance of firms and attend social needs (Vessuri 1998; Casas et al. 2000; Arocena and Sutz 2005a; Rapini et al. 2009; Maculan and Carvalho 2009).

Worldwide, PRO–I interaction has become important to understand how to strengthen NSI. Most of the research has focused on the perspective of the firm (Laursen and Salter 2004; Hanel and St-Pierre 2006; Fontana et al. 2006; Petersen and Rumbelow 2008; Arza and López 2009; Eom and Lee 2009; Rasiah and Govindaraju 2009) or on the perspective of the university (Tornquist and Kallsen 1994; Schartinger et al. 2002; Di Gregorio and Shane 2003; Friedman and Silberman 2003). A few studies have looked at the determinants of PRO–I interactions taking the individual academic researcher as the unit of analysis (Agrawal and Henderson 2002; Landry et al. 2005; Suzigan et al. 2009); others have explored the perspectives of both agents (Lee 2000; Carayol 2004; Balconi and Laboranti 2006; Bekkers and Bodas Freitas 2008; Bittencourt et al. 2008; Intarakumnerd and Schiller 2009; Bodas Freitas and Verspagen 2009; Dutrénit and De Fuentes 2009; Eun 2009a; Joseph and Abraham 2009).

Within each country, despite sharing similar national organizational and institutional contexts (e.g., regulations, culture, and policies) that facilitate or constrain PRO–I interactions, PRO and firms face different incentive frameworks (Nelson 1993; Foray and Steinmueller 2003) and have different motivations for establishing interactions for knowledge exchange. Studies that focus on the perspectives of individual agents provide insights on different aspects of PRO–I interactions (e.g., drivers to connect, motivations, preferred channels of interactions, and benefits), but are limited

in their ability to inform policymakers. Researchers have approached these issues using different units of analysis: institutions, research groups, and researchers from PROs; and R&D managers or industrial researchers from firms. However, the level of effectiveness of different channels of PRO–I interactions in triggering different types of benefits derived from these interactions, which clearly informs policymakers, is still quite uncertain.

Referring to channels of interactions, there is abundant empirical evidence to suggest that the process of knowledge transfer in PRO–I occurs through multiple channels (e.g., human resources formation, open science, informal contacts, consulting relationships, joint and contract research projects, patenting, and spin-offs). From the industry perspective, some authors argue that open science, property rights, human resources, collaborative R&D projects, and networking are the most important channels of knowledge flows (Narin et al. 1997; Cohen et al. 2002; Swann 2002). However, several studies show that knowledge flows are sector and technology specific (Cohen et al. 2002; Schartinger et al. 2002; Laursen and Salter 2004; Mowery and Sampat 2005; Hanel and St-Pierre 2006; Fontana et al. 2006; Bekkers and Bodas Freitas 2008). Different sectors also have different knowledge bases and innovation patterns (Pavitt 1984), and different ways to interact with the academic institutions and other sources of knowledge. From the academic perspective, differences were also found. Meyer-Krahmer and Schmoch (1998) argue that collaborative R&D is the most important knowledge flow in some fields. Bekkers and Bodas Freitas (2008) found that the relative importance of the channels is similar among firms and academic researchers; however, academic researchers assign more importance to the different channels than firms.

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

The literature has identified a set of benefits that may be obtained through PRO–I interactions. From the firm's perspective it was found that firms obtain a different angle for the solution of problems and in some cases perform product or process innovations that without interaction would not have been possible. Firms also benefit from highly skilled research teams, new human resources, and access to different approaches for problem solving (Rosenberg and Nelson 1994). For researchers,

benefits include obtaining additional funding for the laboratories and exchanging knowledge (Meyer-Krahmer and Schmoch 1998), securing funds for research assistants and laboratory equipment, gaining insights for their own academic research, testing applications of a theory, and supplementing funds for their own academic research (Fritsch and Schwirten 1999; Lee 2000). As well, researchers acquire a new perspective on how to approach industry problems and how to shape the knowledge that is being produced at academic institutions (Hanel and St-Pierre 2006).

Less research has been done on the effectiveness of different channels of interaction on the benefits obtained by both agents (e.g., Adams et al. 2003; Arvanitis et al. 2008; Wright et al. 2008). This chapter analyses the relationship between channels of PRO–I interactions and benefits in four Latin American countries (Argentina, Brazil, Costa Rica, and Mexico) from the perspective of both researchers and firms. In particular, we explore what channels of PRO–I interactions are the most effective for triggering the different benefits received by researchers and firms involved in PRO–I interactions.

Following Arza (2010), we assume that benefits associated with PRO–I links are not the same across different forms of interactions. Some forms involve shared intellectual resources and outputs by both PRO and industry based on knowledge flows in both directions, whereas others imply a unilateral provision of intellectual resources from PRO to the firms under different modes. The use of different forms or channels may be associated with a set of motivations that each agent may have for engaging in PRO–I interactions.

We classify channels into four types according to the motivations to engage in links and the direction of knowledge flows. Each channel includes a set of different forms of interaction:

(1) Traditional: related to traditional ways in which firms benefit from PRO activities (e.g., hiring graduates, conferences, and publications) – knowledge flows mainly from PROs to firms, and knowledge contents are defined by the conventional functions of academic institutions (e.g., teaching and research).

(2) Services: motivated by the provision of scientific and technological services in exchange for money (e.g., consultancy, use of equipment for quality control, tests, and training) – knowledge flows mainly from PROs to firms.

(3) Commercial: motivated by an attempt to commercialize the scientific outcomes that PROs have already achieved (e.g., patents, technology licences, spin-off companies, and incubators); knowledge flows mainly from PRO to firms.

(4)   Bi-directional: motivated by long-term targets of knowledge creation by PROs and innovation by firms (e.g., joint R&D projects, participation in networks, contract research, and scientific–technological parks, etc.) – knowledge flows in both directions and both agents provide some knowledge resources.

We classify benefits to firms according to the nature of the activities they impact: (1) production – those oriented to solving short-term production problems (e.g., make earlier contact with university students for future recruiting, perform tests, and help in quality control); and (2) innovation – those oriented to contributing to long-term innovation capabilities and outputs (e.g., augment the firm's ability to find and absorb technological information, complementary research, and substitute research). Based on the nature of the benefits obtained by researchers, we distinguish: (1) intellectual – related to nurturing knowledge skills of PROs (e.g., get inspiration for future scientific research, ideas for new PRO–I collaboration projects, and reputation); and (2) economic – related to accessing additional resources (e.g., provision of research inputs, financial resources, and sharing equipment and instruments).

We claim that benefits are better balanced, and that interactions may have better knowledge value, when bi-directional channels are used and knowledge flows in both directions between the two agents. We assume that the knowledge capability of different agents is behind this type of link. This conceptual framework is further developed in Arza (2010).

The empirical evidence on which we draw our analysis comes from original micro-data collected through surveys on firms and academic researchers (see Introduction, this book). Based on country studies (Arza and Vázquez 2010; Fernandes et al. 2010; Orozco and Ruiz 2010; Dutrénit et al. 2010b), this chapter discusses the results and extracts a set of features of PRO–I interactions, particularly relevant to the relationship between channels and benefits. Although there are important differences between the analysed countries in terms of size of the economy, level of development, sector specialization, and historical roots of PRO–I interactions, they share a weak NSI, which characterizes Latin American countries as well as most developing countries.

HISTORICAL ROOTS OF PRO–I INTERACTIONS

There is a quite common understanding that Latin American NSIs have been largely built from a top-down perspective, as a result of S&T policies based on a supply-push focus associated with the linear model

of innovation. In fact, the evolution of the S&T policies (today Science, Technology, and Innovation [STI] policies) in Latin American countries has followed trends shaped by the dominant innovation model. With the creation of S&T agencies by the 1970s, the supply-push focus and the linear model of innovation were strengthened. Policies have slowly moved toward a more balanced supply–demand and interactive model of innovation.

Universities are one of the main agents of the NSI, and there are differences among countries in the origin of universities. A common feature is that they were initially oriented to undergraduate teaching, and gradually, as research activities became stronger, postgraduate studies were offered (in the second half of the 20th century in the most advanced countries). It is only in the last few decades that a connection between teaching and research could be built, and become the base for a bi-directional channel of PRO–I interaction.

In the last century, few scientists were connected to the powerful groups in society, which helps explain why only science was considered important when economic development plans were designed. Because universities were concerned with human resources formation and only recently with knowledge generation, knowledge supply was disconnected from demand. This pattern limited the perception that PRO–I interactions could be important.

PROs were created under this supply-push focus to address some key sectors (e.g., coffee in Costa Rica, aeronautic and oil in Brazil, oil and energy in Mexico, nuclear technology in Argentina, and agriculture in all countries), but again based on what was considered important for policymakers and researchers. Recent pressures to change the sources of funding of these institutions, by reducing public funding and increasing the resources they must generate themselves, have pushed PROs to look more at the demand side.

Latin American firms have evolved inside a productive structure with unclear incentives. Industrial policies failed to foster competitiveness and integration of productive chains. Firms were able to survive in non-competitive domestic markets in several sectors, without any pressure or incentives to engage in technological learning and building of innovative capabilities. In addition, starting in the 1960s, multinational corporations began to locate subsidiaries in these countries, and had a strong impact on the building of productive structures (Mexico and Costa Rica) or on their evolution (Brazil and Argentina). They helped generate a sort of subsidiary "industrial culture" in the whole productive sector, which was more oriented to production than to R&D and innovation. In fact, evidence about knowledge spillovers suggests that to attract the R&D laboratories of these multinational corporations certain local conditions were required

(e.g., structured talent in local and domestic PROs) (Criscuolo et al. 2005; Marin and Bell 2006; De Fuentes and Dutrénit 2012).

A mismatch is observed in the production of knowledge and technology. The participation of Latin American countries in the worldwide publication of scientific papers is much larger than their participation in the world patents submitted to the United States Patent and Trademark Office (USPTO). The increase in scientific output observed in the last decade has not been accompanied by an increase in applications for patents. This suggests that the scientific side of the NSI has improved at a quicker pace than the business side. These factors help explain the weaknesses of knowledge supply–demand links, PRO–I interactions, and the difficulties in generating the dynamics that characterize a learning society (Arocena and Sutz 2005b).

In the last few decades there has been a gradual change in the institutional setup of PROs toward building links with society – including the business sector, social sector, and social needs. A change can be observed in the line of thought of researchers, authorities in PROs, and other agents, including firms, who now refer to the need for interaction and problem-oriented research. In addition, a shift in S&T policy can be observed in the region toward an increase in incentives that foster bottom-up initiatives and stimulate links; however, the incentives structure is still not properly aligned to foster such interactions.

Nevertheless, research carried out in PROs has led to success in some sectors. Gutiérrez (1993) and León and Losada (2002) highlight the importance of PRO research for upgrading agricultural technology in Argentina; Suzigan and Albuquerque (2009) argue the importance of university research for the development of the aircraft, steel, and agricultural industry in Brazil; and Casas et al. (2000) show the importance of university research to the chemical and other process industries in Mexico. These interactions were based more on human resources formation, information access, training, and other services than on collaborative research. Although these are successful cases, there have been difficulties in maintaining the pace of required changes, extending the links to new sectors, and being proactive in the evolution of the NSI. A more detailed description of the historical roots of PRO–I interactions in the four countries follows.

Argentina

Although universities have grown systematically since the reform that began in Argentina in the early 20th century and was later repeated in other Latin American countries, it was in the 1950s when research

activities gained dynamism. It was also during this period that most PROs were created (e.g., specialized institutes for agriculture [Instituto Nacional de Tecnología Agropecuaria, INTA], industry [Instituto Nacional de Tecnología Industrial, INTI], atomic energy [Comisión Nacional de Energía Atómica, CNEA], and Consejo Nacional de Investigaciones Científicas y Técnicas, CONICET]. Consequently, public spending in S&T increased, although this did not go hand in hand with private sector spending. Imports of capital goods continued to be the main source of technological knowledge for this sector. The spirit of this period reflected the ideas of the linear model of innovation that spread around the world after World War II. It was believed that scientific knowledge was a necessary condition for economic development, and the promotion of PRO–I interaction was relegated.

In the late 1960s and early 1970s a group of Latin American intellectuals (Sábato and Varsavsky, among others)[3] criticized the predominant scientism of S&T policies and insisted on a more active and direct role for the state and for publicly supported institutions in technology development. The problem of development was then viewed as the result of technological dependency. These voices had a strong influence in the policy scene, and specific measures were created to regulate technology flows from abroad and to channel investment in S&T toward targeted strategic sectors. However, probably due to the strong macroeconomic instability of the time, these measures were not sustained and were, therefore, rather ineffective.

The years that followed the military coup of 1976 were characterized by a reversal of the S&T and outreach activities that had been carried out the decade before. The S&T complex was virtually dismantled, and the activities and knowledge outputs from all PROs declined – with the exception of those from the CNEA because of its connection to military technology.

The 1990s marked the period of liberalization policies in Argentina. It was believed that trade liberalization would promote technological innovation because of increased competition and reduced prices of imported capital goods. Policies during this period also relied on foreign direct investment (FDI) as a mechanism for successful international technology transfer. S&T policies prioritized firms as the main actors in the innovation process and, in this sense, the creation of the Agencia Nacional de

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[3] Varsavsky (1973) proposed what López (2007) called a linear model but "the other way around" – society must set the productive priorities from which technological needs are derived. Those needs should be satisfied by the S&T complex. In turn, Sábato (1973) developed the triangle model to emphasize the need of public policies to integrate the three vertexes: the state; the productive sector; and the scientific sector. Sábato's ideas set a precedent to Etzkowitz's "Triple Helix" (Etzkowitz and Dzisah 2007).

Promoción Científica y Tecnológica (ANPCyT) in 1996 and the novel support to PRO–I interactions represented a major institutional reform.

Among other challenges for the Argentinean NSI, we believe there is the need to make much better use of existing capacities in the S&T complex. The Argentinean experience reflected international trends: general support to the linear model of innovation in the 1950s as a strategy for economic development that was later supplanted by the idea that PROs should be more directly linked to productive needs. Therefore, there was wider support to PRO–I interactions especially from the 1990s onward.

Brazil[4]

Brazil is characterized by late development of PROs, which affected their capability building in several fields of science and engineering. The first Brazilian university was founded in 1934, although some higher education schools were established in the 19th and early 20th centuries. Until the 1950s, engineering courses remained limited to mining, metallurgy, agronomy, and construction. Teaching of graduate courses did not start before the late 1960s or early 1970s, and only after this was teaching linked to research activities in influential Brazilian universities. PROs developed relatively earlier to attend local social and economic demands mostly in agriculture and public health, but those related to industrial activities were only founded since the 1950s (Suzigan and Albuquerque 2009).

Late and structurally restricted industrialization created a poor pattern of demand from industries. Until the 1960s, light industrial consumer goods still represented over 50% of Brazilian manufacturing production. After that, industrial policies stimulated a more diversified industrial structure, but failed to promote endogenous technology development, favouring instead the import of technology, thus weakening the process of learning by domestic industries. Currently, Brazilian industry is internationally competitive in commodities like steel, cellulose and paper, food products, and some manufactured goods, the most notable example being aircraft. In all of them, there is a long history of interactions involving different agents (PROs, firms, and government), dimensions (science, technology, and finance), and knowledge fields.

However, the limited number of PRO–I interactions in sectors that are considered strategic for improving the nation's technological skills reflect a poor pattern of demand from industry (Rapini et al. 2009). Important reasons for this are the country's late industrialization process, combined with extreme income concentration, inadequate inward orientation, and

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[4] Based on Fernandes et al. (2010).

many years of high inflation, all of which led to a deeply rooted culture of importing technological packages. This helps to explain why most of the knowledge and technological capabilities in the country are concentrated in PROs.

Although the country shows a marked heterogeneity of interactions between industrial sectors and science and engineering fields (Dagnino and Velho 1998; Bernardes and Albuquerque 2003; Rapini et al. 2009), there are successful cases like the steel industry, petrochemicals, aircraft, and agro-industries. These examples are the fruit of long-term processes of capability building and of learning to interact by both research institutions and production units.

Recent public policies have targeted such interactions to enhance the evolutionary process and drive the creation of scientific institutions to stimulate demand. This has been the case in information and communication technologies, computer sciences, and computer engineering.

The NSI in Brazil is still lagging behind other countries. The Brazilian path is slow and shows a relatively small interaction between scientific and technological production (Ribeiro et al. 2009). The scientific side of the system has improved considerably, but the mismatch with production technology is representative of a less-developed national socioeconomic formation.

Costa Rica[5]

University development in Costa Rica dates back to 1950 with the creation of the University of Costa Rica. During the 1970s, higher education received a major boost with the creation of the Universidad Nacional de Costa Rica (UNA in 1973), the Instituto Tecnológico de Costa Rica (ITCR in 1971), and the Universidad Estatal a Distancia (UNED in 1977). Efforts to enhance scientific and technological infrastructure during these years were trying to improve services to society (e.g., generation and electricity supply, agricultural production, education, health, telecommunications, and transport).

The Consejo Nacional para Investigaciones Científicas y Tecnológicas (CONICIT) was founded in 1972 as a tool to provide more institutional support for research as an engine of scientific development. With this, S&T started to count with the first non-university institutional framework to advise the Government of the Republic and to promote research activities, training of human resources, laboratory construction, and dissemination of science (CONARE 2004).

[5] Based on Orozco (2010).

Universities initially focused on professional training, but have gradually built research capabilities. Starting in the 1980s, they began to encourage links with other sectors of society, especially through the sale of services. Foundations facilitate resource management and interactions with other sectors: in 1982 the Fundación Pro Ciencia, Arte y Cultura de la Universidad Nacional was created (Fundación UNA), in 1987 La Fundación Tecnológica de Costa Rica (FUNDATEC) in the ITCR, and in 1988 the Fundación de la Universidad de Costa Rica para la Investigación (FUNDEVI) (CONARE 2004, p. 16).

As stated by Macaya et al. (2010), the research units of public universities are the backbone of S&T in Costa Rica because they undertake most scientific research. These units have evolved in recent years toward greater integration with society and productive sectors, and gradually abandoned the academic vision they had in the early 1980s.

When studying university–industry links (UILs) in Costa Rica it can be stated that: (1) the research units in agricultural, agrology, and food retain a more constant relationship with businesses; (2) few links are found among research units and there are few joint projects of relevance to the development of S&T; and (3) the productive sectors have not generated enough demand to encourage joint research on specific problems or needs (Macaya et al. 2010).

In addition to the efforts of universities, other PROs have been created, many in the agribusiness sector. Other organizations have been created to access knowledge and technology in subsectors such as coffee, bananas, and sugar, which are led by sectoral organizations with state participation, but also include other private sector actors. In these cases, there is usually a non-state government agency that guides and supports the processes of R&D and focuses on different aspects of production practices. Subsequently, the knowledge and technologies are disseminated to extension or advisory groups, which may be free or charged to users. Examples of organizations include: the Instituto del Café de Costa Rica (ICAFE); La Corporación Bananera Nacional (CORBANA); and Departamento de Investigación y Extensión de la Caña de Azúcar (DIECA).

In August 2009, the Centro Nacional de Innovaciones Biotecnológicas (CENIBIOT) was inaugurated to complement the work of state universities in areas of new development, with a focus on interuniversity, interdisciplinary, and outreach toward productive and governmental sectors.

Most of the links are built with medium and large firms because a high proportion of small businesses do not have the basic skills required for successful links. Mechanisms to strengthen the NSI still need to be developed, particularly those that favour small businesses. The main barriers for more

links are lack of knowledge of the activities of research centres, and lack of knowledge that these centres have about business needs (MICIT 2011). New mechanisms for communication and collaboration between different actors in the NSI are still required.

Mexico

The Mexican NSI is characterized by frail and irregular interactions among key actors (Cimoli 2000; Dutrénit et al. 2010a). The generation, dissemination, and absorption rate of technological knowledge is low, and interactions are mainly restricted to PROs. The Mexican NSI shows poor performance in terms of scientific and technological productivity compared with other emerging economies, as illustrated by the participation in the worldwide publication of scientific papers and world patents submitted to the USPTO. At the base of its fragility we found weak PRO–I links, which have evolved over time as a result of STI policies, institutions, and other incentives.

Higher education in Mexico is rooted in 1910 with the creation of the Universidad Nacional Autónoma de México (UNAM). Other major public and private universities, such as the Instituto Politécnico Nacional (IPN), the Instituto Tecnológico y de Estudios Superiores de Monterrey (ITESM), the Universidad Autónoma Metropolitana (UAM), and various state universities were established between 1930 and 1980. The foundation of IPN in 1936, which was strongly oriented to engineering and technological research, marked a fundamental turning point in the policies, which since then have been oriented not only to higher education but to S&T.

Between 1930 and 1980, almost all public research centres were created, some of them linked to state firms and ministries (e.g., oil, agriculture, and public health), and others oriented to three main scientific and technological areas (mathematics and natural sciences, social sciences and humanities, and innovation and technological development). Most of them emerged from a supply-push perspective, without considering the demands of the productive sector. Therefore, a mismatch emerged from the beginning between the knowledge supply of PROs and the knowledge demand of firms.

The Consejo Nacional de Ciencia y Tecnología (CONACYT) was created in 1970 and became primarily responsible for STI policies. As with other agencies created in Latin America, it adopted the top-down approach that has characterized the NSI scene. The evolution of PROs was moulded by the supply-push policies associated with the linear model of innovation, which was reinforced by CONACYT. PROs concentrate the greatest efforts in S&T. Four public institutions have been of remark-

able importance – UNAM, IPN, UAM, and the Centro de Investigación y de Estudios Avanzados Unidad Mérida (CINVESTAV), which account for nearly 50% of scientific production in Mexico. Most of them are weakly connected to demands from firms.

Weaknesses in the links also emerge from industry. Private R&D expenditure has been weak over time, and the productive sector has largely acted as an isolated actor within the NSI. There is a clear absence of regular links between firms and other economic and social actors, such as PROs. The distortions that inhibit links with PROs are largely economic. Firms within scarcely competitive markets are not steered toward a strategy guided by innovation. Mismatches may also be related to the practices of multinational corporations and large firms in mature sectors, which look at production rather than at innovation, or look for foreign knowledge suppliers. This and other market failures diminish the demand for knowledge provided by domestic PROs. Most firms acquire high percentages of their technology from abroad, which transforms them into technological followers, and defines their relationships with local universities. Because high-tech is imported, Mexican firms demand R&D from PROs that is needed to improve products and processes already available at the international level. Only a handful of corporate enterprises or transnational companies establish more complex interactions with PROs.

The majority of interactions within the NSI have taken place in what may be called a public triad: CONACYT – public research centres – public universities. Nonetheless, some successful cases of PRO–I interactions have emerged in different sectors (Casas et al. 2000; Corona and Amaro 2009).

Recognizing that knowledge generated in PROs plays an important role in driving firm-level innovations, since the early 1990s, the Mexican government has implemented explicit policies to stimulate PRO–I links. They were strengthened at the end of the 1990s with the approval of the Science and Technology Laws in 1999 and 2002, and the Programa Especial de Ciencia y Tecnología 2001–2006 (PECYT). Recent STI programmes have tried to switch from a top-down to a bottom-up system of incentives. Until 2009, the main programmes fostering PRO–I interaction in terms of resources were the R&D fiscal incentives and the sectoral fund for innovation.

METHODOLOGY

This chapter is based on research results from four countries that used common datasets (Arza and Vázquez 2010; Fernandes et al. 2010; Orozco and Ruiz 2010; Dutrénit et al. 2010b). These studies used the econometric models suggested by Arza (2010).

Researchers

$$d\_V = RV_i b + m_i \tag{1.1}$$
$$IB_i = Ch_i a + R_i d + e_i \tag{1.2}$$

$$d\_V = RV_i b + m_i \tag{1.3}$$
$$EB_i = Ch_i a + R_i d + e_i \tag{1.4}$$

Firms

$$d\_V = FV_i b + m_i \tag{2.1}$$
$$PB_i = Ch_i a + F_i d + e_i \tag{2.2}$$

$$d\_V = FV_i b + m_i \tag{2.3}$$
$$InB_i = Ch_i a + F_i d + e_i \tag{2.4}$$

The conceptual framework suggests that different channels of inter-actions (traditional channel TCh_i, service channel SCh_i, commercial channel CCh_i, and bi-directional channel BCh_i) have the potential to trigger different kinds of benefits, both for researchers (intellectual IB_i and economic EB_i) and for firms (benefit related to production activi-ties PB_i and to innovation activities InB_i) (see equations 1.2, 1.4, 2.2, and 2.4). Moreover, there are other researcher and firm features (R_i and F_i) 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 1.2, 1.4, 2.2, and 2.4, can be measured only for the researchers and firms that actually interact. These observed researchers and firms may enjoy special characteristics (which promotes the interaction in the first place). To deal with potential selection bias we suggest the use of Heckman's two-step method. For the selection part of each Heckman model (equations 1.1, 1.3, 2.1, and 2.3), the depend-ent variable (d_V_i) is a dummy variable that equals 1 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 also are informed by the literature.

Because the selection part of the Heckman method estimates the inverse Mills ratio that 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 Bayesian Information Criterion).

All the country studies are based on surveys of researchers and firms. In the case of Mexico and Argentina, both linked and unlinked research-ers and firms were surveyed; in the case of Brazil only linked actors are

included. Therefore, 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 country cases previously agreed about similar proxies for key variables, such as benefits and channels of PRO–I interactions. This allows the results to be compared.

COMPARATIVE ANALYSIS OF CHANNELS AND BENEFITS AMONG COUNTRIES AND AGENTS[6]

Here we compare the main descriptive findings of the four countries by using common datasets and estimating the same econometric models. The first section compares the importance allocated by firms and researchers to the use of different channels of PRO–I interactions. The second section looks at the perceived importance that firms and researchers place on the benefits obtained through PRO–I interaction. To normalize country-specific details, all comparisons are based on the ranking of importance of different channels within each country. Firms and researchers in Brazil tend to be the most positive about all channels and benefits, whereas firms and researchers in Argentina tend to be the most negative. Mexico and Costa Rica are intermediate cases. The third section compares the econometric findings of each country based on the sign and significance of coefficients of key variables, especially on the relation between channels and benefits.

Channels of Interaction

Three findings were common to all countries. First, the commercial channel is relatively unimportant for all forms of interaction it represents (Tables 3.1 and 3.2). This result confirms what has been found by other authors looking at advanced economies (Cohen et al. 1998; Meyer-Krahmer and Schmoch 1998; Agrawal and Henderson 2002; Cohen et al. 2002; D'Este and Patel 2007). Second, informal interactions through conferences or other types of informal information exchange are relatively important, as was also found by Cohen et al. (2002), Meyer-Krahmer and Schmoch (1998), and D'Este and Fontana (2007). Third, researchers in the four countries tend to assign higher importance to any channel other than firms, as was also found by Bekkers and Bodas Freitas (2008) for another region.

   Regarding important channels, the agreements across agents and countries are slightly weaker. Researchers in Brazil and Costa Rica tend to prefer traditional channels (especially publications and conferences),

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[6] This section draws on Dutrénit and Arza (2010).

Table 3.1   Importance of channels of interaction for researchers (% of moderately and very important)

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

Sources: Arza and Vázquez (2010); Dutrénit et al. (2010a); Fernandes et al. (2010); and Orozco and Ruiz (2010).

whereas in Argentina they prefer the service channel (consultancy), and in Mexico the bi-directional channel (joint R&D). However, when the four most important channels are called upon, in all countries either joint or contract research (bi-directional channels) are important to researchers.

Table 3.2   Importance of channels of interaction for firms (% of moderately and very important)

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

Sources: Arza and Vázquez (2010); Dutrénit et al. (2010a); Fernandes et al. (2010); and Orozco and Ruiz (2010).

Table 3.3   Importance of benefits from interaction for researchers (% of moderately and very important)

Benefits	Argentina		Brazil		Costa Rica		Mexico	
	%	Rank	%	Rank	%	Rank	%	Rank
Intellectual								
Inspiration for future scientific research	70.0	2	85.9	1	76.5	5	0.70	3
Share of knowledge and information	75.0	1	81.8	2	89.8	2	0.66	4
Ideas for new PRO–I collaboration projects	66.0	3	81.6	3	87.8	3	0.73	1
New social networks	–	–	72.3	4	70.4	6	–	–
Reputation	56.0	5	70.6	5	92.9	1	0.65	5
Economic								
Provision of research inputs	45.0	6	70.1	6	60.3	7	0.56	7
Financial resources	64.0	4	69.8	7	78.4	4	0.61	6
Share equipment and instruments	35.0	7	53.9	8	48.9	8	0.73	1

Sources: Arza and Vázquez (2010); Dutrénit et al. (2010a); Fernandes et al. (2010); and Orozco and Ruiz (2010).

In contrast, in the case of firms, the agreement among countries in the use of channels refers to the traditional channel, in particular hiring recent graduates. Other studies have found that this form is important, but not one of the most important channels from the firms' perspective.

Benefits from Interaction

Researchers in all countries tend to mention intellectual benefits more often than economic benefits as the most important benefits triggered by interactions (Table 3.3). They seem to get inspired by the interaction with firms to pursue further research, confirming results obtained by several authors (e.g., Fritsch and Schwirten 1999; Lee 2000).

Firms tend to connect to PROs for short-term problem solving rather than to get insights for their longer-term innovative strategies (Table 3.4). One of the benefits most frequently mentioned as important in Argentina, Brazil, and Mexico is to perform tests, and in all countries, including

Table 3.4   Importance of benefits from interaction for firms (% of moderately and very important)

Benefits	Argentina		Brazil		Costa Rica		Mexico	
	%	Rank	%	Rank	%	Rank	%	Rank
Innovation								
Augment the firm's ability to find and absorb technological information	18.0	7	57.4	7	51.0	4	40.0	4
Technology transfer from PRO	21.0	5	60.1	3	43.0	8	39.0	6
Contract research to contribute to firm's innovative activities (complementary)	–	–	58.3	5	48.0	6	39.0	6
Contract research that firms do not perform (substitute)	13.0	9	58.0	6	32.0	10	38.0	8
Get information about engineers or scientists and trends in R&D in the field	17.0	8	47.2	8	52.0	2	37.0	10
Production								
Make earlier contact with university students for future recruiting	25.0	4	37.1	9	52.0	2	47.0	1
Perform tests necessary for products and processes	43.0	1	63.19	1	39.0	9	44.0	2
Obtain technological advice from researchers to solve production-related problems	30.0	3	59.5	4	62.0	1	43.0	3
Use resources available at PRO	20.0	6	61.7	2	50.0	5	40.0	4
Help in quality control	38.0	2	27.9	10	48.0	6	38.0	8

Sources: Arza and Vázquez (2010); Dutrénit et al. (2010a); Fernandes et al. (2010); and Orozco and Ruiz (2010).

Costa Rica, to obtain technological advice to solve production-related problems. Access to skilled human resources appears as an important benefit for firms, particularly in the case of Mexico. Nevertheless, in the case of Brazil and Costa Rica, firms pointed out benefits related to their innovation activities: Brazilian firms seem to benefit from the transfer of technology from PROs, and Costa Rican firms claimed that by interacting they got information about novel trends in R&D.

Channels and Benefits

This section discusses empirical findings from four countries based on similar econometric models that relate four channels of interactions with different types of benefits for both agents. Although there are country-specific findings, the main results on the relation between channels and benefits are consistent across most countries. This section summarizes the results of studies in Argentina (AR), Brazil (BR), Costa Rica (CR), and Mexico (MX) (Arza and Vázquez 2010; Dutrénit et al. 2010b; Fernandes et al. 2010; and Orozco and Ruiz 2010) (Tables 3.5 and 3.6).

Researchers received intellectual benefits mainly through the service (AR, BR, CR), the bi-directional (AR, BR, MX), and the traditional (AR, BR, MX) channels, whereas the commercial channel seems to negatively affect the creation of intellectual benefits for researchers in PROs (AR, BR, MX) (Table 3.5). In turn, economic benefits are driven mainly by the service channel (AR, BR, CR). Some country specifics can be

Table 3.5   Determinants of benefits for researchers: channels of interaction

Country	Intellectual benefits				Economic benefits			
	TCh	SCh	CCh	BCh	TCh	SCh	CCh	BCh
AR		***	(–)**	***		***		
BR	***	***	(–)***	***	***	***		***
CR		*				*		*
MX	*		(–)***	**				

Notes: T traditional; Ch channel; S service; C commercial; B bi-directional;
AR Argentina; BR Brazil; CR Costa Rica; and MX Mexico.
* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.
In the case of Brazil, data correspond to interactions with universities.

Sources: Arza and Vázquez (2010); Dutrénit et al. (2010a); Fernandes et al. (2010); and Orozco and Ruiz (2010). See Dutrénit and Arza (2010) for definitions of the variables for all countries.

Table 3.6   Determinants of benefits for firms: channels of interaction

Country	Production benefits				Innovation benefits			
	TCh	SCh	CCh	BCh	TCh	SCh	CCh	BCh
AR	**			**	**			***
BR	**	**		**	**			***
CR	*			*	*	*		*
MX	*	*		**		*		**

Notes: T traditional; Ch channel; S service; C commercial; B bi-directional;
AR Argentina; BR Brazil; CR Costa Rica; and MX Mexico.
* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Sources: Arza and Vázquez (2010); Dutrénit et al. (2010a); Fernandes et al. (2010); and
Orozco and Ruiz (2010). See Dutrénit and Arza (2010) for definitions of the variables for
all countries.

highlighted: in Brazil and Costa Rica the bi-directional channel was sig-
nificant for obtaining economic benefits; in Costa Rica, the bi-directional
channel was important for obtaining economic rather than intellec-
tual benefits; and in Mexico no channel was important for obtaining
economic benefits.

Table 3.6 shows that firms obtain benefits related to their production
activities mainly through the traditional and bi-directional channels in all
the countries. These channels also work as important drivers of benefits
related to innovation activities: the traditional channel was significant
in the case of Argentina, Brazil, and Costa Rica, and the bi-directional
channel in all countries. Moreover, the service channel was also a key
driver of production benefits (BR, MX) and of innovation benefits (CR,
MX).

Each country study included control variables that best fit their model
(Arza and Vázquez 2010; Fernandes et al. 2010; Orozco and Ruiz 2010;
Dutrénit et al. 2010a). This means that neither the same concepts were
included as control variable nor the same proxies for similar concepts.
Therefore, it is not possible to establish strict cross-country comparisons.
Nevertheless, some common patterns can be drawn for the data for firms.
First, the innovative capabilities of firms seem to be a positive driver of
benefits (AR, MX), although the effect is negative in the case of Brazil.
Second, small firms seem to obtain better benefits (AR, CR). Third,
although public support for innovation was found as a positive driver for
interactions, linked firms that receive public support seem to receive lower
benefits of PRO–I interactions than otherwise (BR, MX), although in
Costa Rica the effect on benefits is positive.

DRIVERS OF INTERACTION

Although this discussion focuses on the characteristics of channels and benefits of PRO–I interactions across countries, some insights can be obtained about the drivers of interaction by taking advantage of the participation equation estimated by the Heckman model (which estimates the determinants for an actor to be connected to its partner). As a by-product of the previous analysis, this section briefly compares drivers of interactions among those countries that have data on linked and unlinked actors (i.e., Argentina, Mexico, and Costa Rica, although the last only for firm data). Table 3.7 shows the drivers for researcher and firm interactions.

Two common drivers are observed for the researchers in the cases of Argentina and Mexico: those that belong to research groups and those researching in areas that learn from application are more likely to be connected to firms. In addition, male researchers in the case of Argentina, and researchers without postgraduate degrees and from PROs instead of universities in the case of Mexico, are more likely to connect.

There is one common driver for firms in Argentina, Costa Rica, and Mexico: access to public support for innovative activities (i.e., some sort of fiscal subsidy for innovation activities). Recent innovation policy instruments seem to be effective in fostering PRO–I interaction. Our evidence for the three countries shows that firms that received public support were more likely to connect. In Argentina and Costa Rica, large firms are more likely to connect to PROs; and in Mexico and Argentina, a firm's strategy of networking, and for getting access to external information, is a driver of PRO–I interaction. Only in Costa Rica is a firm's innovativeness, as measured by R&D expenditure, a driver of PRO–I interaction, which means that particularly innovative firms are more likely to connect. This suggests that innovative firms either look for other external sources of knowledge than domestic PRO or carry out innovation activities that do not require external knowledge.

FEATURES OF PRO–I INTERACTION IN LATIN AMERICA

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

(1)   Two drivers of interaction for researchers are common in the countries: (a) belong to research groups; and (b) conducting research in

Table 3.7   Main drivers of interactions for researchers and firms

	Argentina	Costa Rica	Mexico
Firms	**Public support** [fin_pub_id*] **Networking** [network***, (-) oth_link_info***] **Sector networking** [sector_link***] **Size** [decile_workers***]	**Public support** [fin-pub_ai**] **Sector networking** [rama_link**] **Size** [decil_obreros*] **Innovativeness** [inhouse_vtas***]	**Public support** [fiscal incentives for R&D**] **Networking** [openness F4**] **Use of open information** [openness F1***] **Perception PRO–I** [perc. role of PRO in creation & transfer of know***]
Researchers	**Research field** [pasteur***] **Perception PRO–I** [perc_PRO–I***] **Research group size** [size_rg**] (-) **Female** [gender**]	N/A	**Research field** [(-) medicine**, biotech & agronomy***, engineering***, base category: physics and maths] **Basicness** [basic science***, techno develop***, base category: applied science) **Perception PRO–I** [perc. importance linking***] **Team** [member of research team***] (-) **Knowledge skills** [(-) master**, (-) phd***, base category: graduates] (-) **University** [(-) type of org***]

Note: Significant drivers are named by the general concept they represent and the variable name is given between square brackets. See Dutrénit and Arza (2010) for definitions of the variables for all countries.

Sources: Arza and Vázquez (2010); Dutrénit et al. (2010a); and Orozco and Ruiz (2010).

areas that are directly influenced by both the quest of fundamental understanding and the quest of applied use. Therefore, these researchers learn from the application of knowledge.[7] A common driver of interaction for firms is access to public support for innovation activity.[8]

(2) The channels of interaction most frequently used by researchers and firms in all countries are the service and the traditional channels. In particular, agents in all countries seem to prefer informal forms of interaction and those that involve the training of human resources.

(3) There are differences in the knowledge that is appropriated by researchers and firms. The most important benefits of PRO–I interactions for researchers are the possibility of pursuing further research in the future (i.e., intellectual), whereas the most important benefits of PRO–I interactions for firms are their contribution to short-term production activities rather than to long-term innovation activities.

(4) Firms that receive public support are more likely to establish links with PROs, but they do not necessarily obtain higher benefits from those interactions.

(5) All channels of PRO–I interactions, except the commercial one, trigger positive intellectual benefits for researchers. When PRO–I interactions use the commercial channel, intellectual benefits are reduced.

(6) PRO–I interactions that use bi-directional and traditional channels are the most effective triggers of both production and innovation benefits for firms.

FINAL REFLECTIONS

This chapter has drawn on literature about PRO–I interactions to explore the effectiveness that channels of interaction have on benefits for researchers and firms in four Latin American countries. The cited literature was mostly based on evidence from advanced economies and placed more attention on the channels associated with knowledge creation. But most Latin American firms do little R&D or do not carry out any at all. Therefore, those channels that have an impact on other dimensions of business performance must be analysed. We found that the effectiveness

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[7] According to Stokes (1997), research is divided into four quadrants: the Bohr quadrant includes basic research; the Edison quadrant includes traditional applied research; the Pasteur quadrant includes basic research that is inspired by application; and lastly there is an empty quadrant that corresponds to research that is neither inspired by use nor fundamental understanding.

[8] This result is consistent with findings from Korea (Eom and Lee 2010).

of different channels of PRO–I interactions in triggering different types of benefits differed for each agent, and also among agents.

The four countries have idiosyncrasies – differences in terms of size and competitiveness, and different intensities of public support to STI activities. However, they share some characteristics: their NSIs are still immature; the paths of evolution of their PROs are similar; their productive structures and firms are immature; their incentives structures do not foster PRO–I interactions; and the paths of their STI policies are similar. In this sense, although our observations refer to these countries, our results do give insights about Latin America.

Researchers were quite positive in relation to their interactions with the private sector; they were on average more positive than the average firms. This finding has been replicated elsewhere (Bekkers and Bodas Freitas 2008). The frequency with which different channels of interactions were used differed across countries. There was one common agreement: the commercial channel (e.g., patents, incubators, and spin-offs) was the least used. In contrast, in the case of Korea, this is today an important channel, particularly for patents (Eom and Lee 2009). This result illustrates that these countries are at different stages of the catching-up process. Unlike most of the Latin American countries, Korea is competing at the technological frontier, for which it needs to be active in the generation of new knowledge and its industrial application. As countries evolve, it would be expected that the commercial channel would assume more relevance.

Researchers claimed that the main benefits they received from their interactions were related to their intellectual activities, mainly to get inspiration for future research. In fact, the traditional, the bi-directional, and the service channel (i.e., all channels of interactions except for the commercial channel) drive intellectual benefits in most countries. This confirmed results in advanced economies (Fritsch and Schwirten 1999; Lee 2000), but contrasted with Latin American-based literature that claimed that researchers were pressed to interact with the private sector because of budget pressures (Arocena and Sutz 2005b). Still, in agreement with that literature, there were economic benefits associated to PRO–I interactions that were mainly driven by the service channel. Because PROs in Latin America are largely underfinanced and the service channel drives economic benefits, the positive effect that this channel exerts on intellectual benefits must be controlled by the increase in budget, as suggested by Defazio et al. (2009).

We also found a worrisome result: the commercial channel drove negative intellectual benefits for researchers. It can be argued that, through the commercial channel, intellectual benefits may be appropriated by the private sector. This raises issues of concern regarding the risks of privatization of publicly created knowledge in PRO–I interactions. This may have perverse

socioeconomic consequences because the privatization of knowledge created in PROs may affect research downstream and in future generations.

In general, firms claim that PRO–I interactions contribute to their short-term production activities rather than to long-term innovation activities. Firms tend to use the traditional channel (e.g., graduates, publications, and conferences) more often than any other channel. However, it is the bi-directional channel (the channel that includes forms of interactions through which knowledge flows in both directions, e.g., joint research) that drives better benefits, especially benefits related to innovation activities.

The bi-directional channel may be most appropriate for transmitting tacit knowledge. Given that tacit knowledge usually conveys more novelty than codified knowledge, the outputs triggered by this channel of interaction could be more path breaking in terms of solving technological bottlenecks. This may explain the large agreement among firms in all countries regarding the effectiveness of the bi-directional channel. The literature suggests that hiring human resources is an important form of interaction; it is one of the most important channels for firms in the Latin American cases analysed here.

Mazzoleni and Nelson (2007) argue that PRO–I interactions can only be effective if there is a proactive demand for knowledge in these countries. Latin American countries are characterized by: a lack of industry demand for sophisticated technological knowledge (Dagnino and Velho 1998; Moori-Koenig and Yoguel 1998; Sorondo 2004; Vega-Jurado et al. 2007); a low demand for domestic sources of knowledge (foreign firms demand technology from their headquarters and many local firms prefer to import technologies) (Velho 2003); and a productive structure that is rather poor in using knowledge assets and therefore draws less from PROs (Casas et al. 2000; Arocena and Sutz 2005a). Consequently, PROs find few opportunities for application. Our evidence on the most important channels of interactions for firms from these four countries suggests that firms continue to lack such proactive demand.

There were also differences in the appropriation of knowledge through the PRO–I interactions: whereas firms look at the short term, researchers are looking long term. The ability to appropriate knowledge through PRO–I interactions seems to depend on the knowledge capabilities of the agent. In fact, the evolution in the worldwide production of the main outputs of both agents (papers and patents) suggests there are different strengths of knowledge capabilities (e.g., participation in papers is much higher than in patents and has grown at a higher rate). It seems that the scientific capabilities of PROs have been built at a quicker pace than the innovation capabilities of firms. This may have impact on the nature of PRO–I interactions and the strength of the NSI. This result is in line with

the findings of the research on Asian countries in this book, which argue that the capabilities of the agents (firms and research laboratories) affect the channels of interaction they use (see Chapter 2, this book).

A policy implication of our findings is the importance that firms give to public support for innovative activities as a driver to get connected. This confirms the effectiveness of recent policies to promote PRO–I interactions, although there is room for improvement. The importance of the recently hired graduates from the firms' perspective suggests that they could be seen as an important interface between researchers and firms. This calls for new STI policies that work with undergraduates to foster changes in firms' behaviour toward innovation activities and better PRO–I interactions, i.e., strengthening the bi-directional channel.

The negative effects of the commercial channel on intellectual benefits raise concerns about the "tragedy of the scientific commons" (Nelson 2004), which may occur if PRO–I interactions imply a privatization of knowledge that formerly belonged to the stock of public knowledge. This may have clear socioeconomic consequences, and it is particularly relevant in developing countries where large firms have better access to IPR mechanisms than many PROs. Although recently policymakers have been particularly concerned with fostering knowledge transfer through patents (which is part of the commercial channel in our framework), evidence shows that this is not currently an important form of interaction in Latin American countries. Therefore, emphasis on foster patenting activity does not seem to be the most efficient way to strengthen PRO–I interactions and the articulation of supply and demand for knowledge in these countries. As the NSI of these countries mature and firms and PROs increase their capabilities, patenting can be expected to acquire more relevance, as is the case in Korea (Eom and Lee 2010). In the case of China, licensing of patents held by universities has become increasingly important (Eun et al. 2006). Evidence of the positive effects of start-ups, another form of interaction in the commercial channel, was found in the case of Brazil (Maculan and Carvalho 2009).

There is now wide consensus that the linear model of innovation does not work properly: very few externalities will be created if PROs are left to produce scientific outputs independent of the needs of society (Kline and Rosenberg 1986). However, the social relevance and quality of PRO research and teaching activities must be preserved for the development process, which calls for a balance between satisfying the demands coming both from the industry and from society. In fact, there is a pressing need to think further about the role of PROs for economic development.

4.   China's university–industry links in transition

Jong-Hak Eun, Yi Wang, and Guisheng Wu

For the first few years after the foundation of the People's Republic of China in 1949, the Chinese leadership encouraged universities to participate in industrial and agricultural production to buttress country-wide collective efforts to rehabilitate an economy devastated by civil war. The government asked universities to divert existing laboratories, pilot plants, and farms originally designed for training students to real production. Responding to the government's call for "spare time production" and hoping to alleviate their own shortage of funds, universities set up "production committees" and tried to mobilize faculty members and students in industrial and agricultural production.

China began to emulate the Soviet Union with its 1st Five-Year Plan (1953–1957). The salient features were enhanced central planning and the extended division of labour among different institutions (e.g., universities, public research institutes, and industrial firms). The engagement of universities in industrial or agricultural production was discouraged. Furthermore, universities were insulated from scientific research, which was regarded as the domain of public research institutes, such as the Chinese Academy of Sciences and other research institutes affiliated with various ministries. As a result, universities were largely restricted to education and training. Not until the early 1960s could universities apply to the government budget for scientific research (MOE 1999). Chinese universities in the early and mid-1950s were thus "teaching universities."[1]

The convergence with the Soviet Union was interrupted in the late 1950s. The Great Leap Forward (GLP) initiated by Mao Zedong changed the role of universities and university–industry relations in China. During the GLP (1958–1960), universities were forced to mobilize their resources to achieve higher levels of production and economic growth. Under the

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[1] Etzkowitz and Webster (1998) suggest that there are three different university regimes – teaching universities, research universities, and entrepreneurial universities.

guiding principle of "combining education and production," many universities established university-run factories (*xiaoban gongchang*) and farms (*xiaoban nongchang*) and arranged for their faculty members and students to carry on a dual mission – academic work and productive labour (Zhang 2003). Although accurate statistics are not available, employees, fixed assets, and output value of those factories and farms allegedly increased greatly during the GLF (Yuan 2002). These university-run factories were the predecessors of the university-run enterprises (UREs) that prevailed in Chinese high-tech industries during the 1980s and 1990s (Eun 2009b). Although most of those factories fell far short of "high-tech" firms,[2] the modern Chinese tradition of university engagement in economic activities, or "academic entrepreneurship," was primarily formulated during this period.

However, the catastrophic result of the GLF together with natural disasters in the late 1950s and early 1960s inevitably entailed a period of adjustment.[3] With the issuance of the Eight Letter Guideline (i.e., *tiaozheng* [adjustment], *gonggu* [consolidation], *chongshi* [supplement], and *tigao* [improvement]) in 1961, university-run factories and farms were largely retrenched or disbanded. The Ministry of Education asked universities to retreat from their "reckless" engagement in non-academic activities. In 1963, the Ministry of Finance finally began to allocate government funds to universities for academic research. This measure can be understood as an official encouragement for universities to focus more on academic research rather than direct engagement in real-world production.

During the Cultural Revolution (1966–1976), the system of higher education and academic research was severely disrupted. Universities stopped recruiting students and already-enrolled students were sent out to rural areas to participate in agricultural or industrial labour. Manufacturing factories affiliated with universities expanded during this period. Many universities established plants and shops, and faculty members were diverted to production from academic research. This period could be characterized as the second boom of UREs. However, these UREs were not actually the agencies that brought scientific knowledge to the industrial

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[2] Mainly focusing on education and training, Chinese universities had only limited, if any, capacity to conduct research and development (R&D). Therefore, even firms affiliated with universities could rarely use state-of-the-art scientific knowledge or new engineering technologies in their business operations.

[3] The GLF ended in catastrophe as it triggered a huge decrease in agricultural and industrial outputs and a widespread famine that resulted in up to 30 million deaths (Bannister 1987; Lieberthal 1997).

sector, because the academic functions in universities almost came to a halt during the Cultural Revolution.[4]

With the initiation of the reform and open door policy (Reform) in 1978, the system of higher education and academic research began to recover in China. At the same time, the direct engagement of universities in industrial work was retrenched. However, it was not just a simple repetition of the adjustment measures taken in the early 1960s. The new leadership led by Deng Xiaoping clearly requested universities to contribute to the economy through science and technology (S&T), although it put limits on large UREs. The new leadership argued that universities should not confine themselves to an "ivory tower." The focus of university research was to be on applied research, which was believed to have a closer relationship with economic development, rather than with basic research (MOE 1999, pp. 34–35).

One salient feature of the Reform was decentralization. More power was delegated from the central planning board to the lower-level agencies. Consequently, the autonomy of individual institutions was expanded and their economic incentives were strengthened. Universities were not exceptions to these far-reaching changes. The Reform allowed universities more room to manoeuvre their resources (e.g., S&T knowledge, human capital, and social networks) to satisfy their own interests. Furthermore, in 1986 the Chinese government began to drastically cut grants to universities due to reforms in the system for appropriating S&T funds (*bokuanzhi gaige*). Consequently, universities had to find alternative sources of funds to survive financially.[5] In short, universities were deprived of government grants, but endowed with enhanced autonomy by the Reform, and became active in commercially exploiting their internal resources.

At the early stage of the Reform, the Chinese government believed that S&T knowledge created in universities could be smoothly transferred to industrial firms through a "technology market." However, it soon became clear that the technology market did not work because of extremely high transaction costs and the lack of relevant institutions. Few Chinese firms were able to absorb S&T knowledge from academic institutions because they had specialized only in production and did not have their own R&D. This made it difficult for Chinese universities to find appropriate partners

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[4] Some research projects, in which the central government was especially interested, were continued or even initiated during this period. For example, 820 research projects on nuclear energy undertaken by Tsinghua University, and 748 research projects on computerized laser typesetting undertaken by Peking University, were initiated during the Cultural Revolution. Beida Fangzheng, Peking University's largest firm, grew out of these 748 projects (MOE 1999).

[5] The share of government grants to university research, which had been 54% in 1986, fell to 23% in 1995 (Institute of Policy and Management 1995).

in the "market" to whom they could transfer S&T knowledge. Even if they could find a partner, valuation of technology and intellectual property disputes stifled the transaction of technologies in the market.

Against this backdrop, a consensus was gradually reached that a more realistic way to harvest economic gains from S&T knowledge held by Chinese universities was to allow them to establish their own high-tech firms.[6] Policy measures resulted in a rapid increase of high-tech UREs in the late 1980s and 1990s. Many UREs (e.g., *Beida Fangzheng* and *Tsinghua Tongfang*) were successful because they enjoyed exclusive or at least preferential access to research findings and other tangible and intangible assets of their mother universities (Eun et al. 2006). As a consequence, UREs had become an important part of high-tech industries and an effective channel of knowledge industrialization in China by the end of the 20th century.[7] However, alternative channels of university–industry links (UILs) had not yet been activated in China (Eun et al. 2006).

More recently, UREs have lost importance in China. They are contributing less to university revenues than before (Wu 2010). The Chinese government no longer encourages universities to directly engage in industrial production through UREs. Rather, the government officially launched reforms of UREs in 2001, aiming to separate firms (UREs) from universities (Eun 2009b). By severing the administrative ties between universities and their affiliated UREs, which resulted in vertical UILs, the Chinese government is now trying to foster horizontal UILs that involve ordinary firms not affiliated to a particular university. Although thousands of firms are still affiliated to Chinese universities and are often (incorrectly) referred to as UREs, they are no longer run or administratively controlled by the universities. Most of them have transformed themselves to limited liability companies (*youxian zeren gongsi*), and universities assume limited roles as (co-)investors in these companies. This implies that the URE model, or the Chinese vertical channel of knowledge industrialization, has gradually faded away.

A transition is going on in the mode of knowledge transfer from university to industry in China. Vertical UILs (represented by UREs) might be expected to give way to emerging horizontal UILs. However, research on horizontal UILs in China has not been undertaken. To explore this

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[6] After witnessing some promising cases, the Chinese government launched the Torch Program in 1988 to further facilitate self-commercialization efforts by universities and public research institutes. Orcutt and Shen (2010, p. 33) argued that the Torch Program, unlike the earlier "technology market" approach, proved to be quite successful at spurring technology transfer from academia to the market place.

[7] There were 6634 UREs, including 2564 high-tech UREs, in 1997 (MOE 2002, p. 10). In 2002, 14 of the 100 top Chinese S&T firms were UREs (Digi Times 2002).

unknown field, we conducted two surveys, one of firms and the other of university professors. The survey results were used to characterize Chinese horizontal UILs and draw policy implications useful to China and other developing countries.

SURVEY DATA

To explore China's emerging horizontal UILs, we conducted two questionnaires in December 2007 and January 2008. One was directed at technology managers in industrial firms and the other at university professors in mainland China. In the firm survey, we followed the basic design of the Carnegie Mellon Survey (Cohen et al. 2002) with some adaptations that reflected the Chinese context. The professor survey was prepared to examine issues from the point of view of the professors.

Our sample for the firm survey was obtained from these three sources: (1) the list of Chinese large manufacturing firms from the 2006 Yearbook of the Chinese Large Manufacturing Firms;[8] (2) the list of member firms registered in the Chinese Private Science and Technology Entrepreneurs' Network (*zhongguo minying keji wang*) (www.mykj.gov.cn/group.aspx); and (3) the list of member firms registered in China Small- and Medium-size Enterprise (SME) Online (www.sme.gov.cn).[9] The second and third groups were added to lessen the expected bias in the first group toward state-owned, large-scale enterprises.

In our survey, firms that did not disclose their phone numbers were excluded because our survey was conducted by phone. We collected phone numbers from 2484 firms, and our survey team contacted the technology manager or the equivalent in each firm to complete the questionnaire. When the targeted interviewee did not answer the phone, our survey team tried calling at least three times to make contact. Through this process, we completed 302 questionnaires (102 from the first group, 73 from the second group, and 127 from the third group), yielding a response rate of 12.2%. Table 4.1 shows the basic sample characteristics in terms of geographic location, ownership type, and scale.

The majority of the sample firms are located in the eastern coastal area (i.e., Beijing, Shanghai, Tianjin, Hebei, Shandong, Jiangsu, Zhejiang, and Guangdong), which is the most populated and the most industrial-

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[8] Large manufacturing firms are defined as manufacturing firms (both indigenous and foreign invested) with more than 2000 employees, RMB 300 million sales revenues, and RMB 400 million total assets in China (RMB1 = USD 0.16).

[9] Membership in China SME Online is only available to small- and medium-size firms that fall short of the requirements of large enterprises.

Table 4.1 Location, type of ownership, and number of employees in firms included in survey

	Sample source			Total firms	%
	Group 1	Group 2	Group 3		
Location					
East	60	64	117	241	79.8
Mid	29	6	7	42	13.9
West	13	3	3	19	6.3
Ownership type					
State	63	0	32	95	31.5
Collective	2	1	3	6	2.0
Private	20	70	67	157	52.0
Foreign	17	2	25	44	14.6
Number of employees					
1–20	0	19	16	35	11.7
21–50	0	24	18	42	14.0
51–200	0	19	27	46	15.3
201–1000	0	10	38	48	15.9
1001–5000	66	1	18	85	28.2
5001+	35	0	10	45	15.0

Notes: Three sources: Group 1 includes large manufacturing firms – 102 respondents (one did not supply information on size of firm); Group 2 includes firms in S&T entrepreneurs network – 73 respondents; and Group 3 is SMEs – 127 respondents. See text for details. Mean number of employees was 2834; median was 600.

ized region in China. Among the sample firms, were 58% private, 32% state-owned, and 15% foreign-invested enterprises (Table 4.1). Scale was measured by number of employees. The sample firms belonged to various industrial sectors, among which machinery and equipment, information technology and electronics, biomedical, petrochemical, and textile and clothing account for more than 55% of the total sample (Table 4.2). These sample characteristics indicate that our sample accurately reflects the main features of the Chinese economy.

The professor survey was conducted differently. First, we shortlisted Chinese universities that had a University Science Park (*daxue kejiyuan*) authorized by the central government in three different major regions (i.e., Beijing and Tianjin, Shanghai, and Guangzhou). We assumed that Chinese universities with a University Science Park had both a strong research capability and a willingness to participate in industrializing scientific knowledge. We confined our survey to these universities, and further

Table 4.2   Industrial sectors in which firms in the survey were active

Sector	Number of firms	%
Machinery and equipment	53	17.5
Information technology and electronics	41	13.6
Biomedical	32	10.6
Petrochemical	24	7.9
Textile and clothing	18	6.0
Construction	14	4.6
Metal and mineral product	13	4.3
Agriculture	12	4.0
Food processing	11	3.6
Transportation and warehouse	11	3.6
Real estate	11	3.6
Post and stationery	11	3.6
Electric power, steam, and water supply	8	2.6
Mining	6	2.0
Paper and printing	6	2.0
Retail and wholesale	6	2.0
Public utilities	1	0.3
Other manufacturing	14	4.6
Other service	10	3.3
Total	302	100.0

narrowed the focus of the survey to the following four major research fields: (1) information technology (IT), including electronics, telecom, and computers; (2) biomedical technology (BT); (3) chemical engineering (CE); and (4) mechanical engineering (ME), including machine, automotive, and shipbuilding. Through this filtering, we selected 1238 professors in 24 universities as our interviewees. As in the firm survey, our survey team contacted the professors by phone and completed 203 questionnaires (a response rate of 16.4%). The basic sample characteristics in terms of geographical location and academic field are shown in Table 4.3.

NEWLY EMERGING UILs IN CHINA

UREs were previously an important channel through which Chinese universities could directly engage in (or contribute to) the economy and transfer their S&T knowledge to industry. With the legacy of a planned economy that rarely allocated R&D to industrial firms, Chinese universities have found it difficult to find capable industrial partners to transfer

Table 4.3 Locations and academic fields of respondents in professor survey (total of 203 professors from 24 universities)

	Location			Academic field			
	Beijing and Tianjin	Shanghai	Guangdong	IT	BT	CE	ME
Professors (no.)	120	69	14	63	53	39	48
Professors (%)	59.1	34.0	6.9	31.0	26.1	19.2	23.7
Universities	14	8	2	–	–	–	–

Note: IT information technology including electronics, telecom, and computers; BT biomedical technology; CE chemical engineering; and ME mechanical engineering.

S&T knowledge. Somewhat inevitably, the Chinese universities have internalized (or vertically integrated) manufacturing based on their own scientific research, and established their own firms (the UREs). Although UREs were once the dominant channel of knowledge industrialization in China, they have been gradually replaced as UREs have been reformed and the absorptive capacity of Chinese firms has been enhanced. Simultaneously, UILs in China have changed from vertical to more horizontal.

These horizontal links between universities and industry can take various forms: joint research; patent licensing; personnel exchange (including professors and graduate students); technological consultations; public conferences and meetings; and informal information exchange. The channels for these links cannot be equally used because of differences in the effectiveness of each channel and in their actual use, which are affected by country-specific conditions. We examined the newly emerging horizontal UILs in China, with special attention to the Chinese characteristics. Because the design of questionnaires used in this study followed the Carnegie Mellon Survey for UILs in the US, we were able to make some international comparisons. More specifically, we tried to answer the following questions: (1) Which channels of UILs are preferred by firms and university professors in China? (2) How important are universities as sources of innovative knowledge for Chinese firms among other alternative sources? (3) How do different types of Chinese firms and universities make links with each other? (4) What will the future development of the Chinese UILs look like?

Main Channels of UILs in China

In general, Chinese professors think that UILs have been strengthened in recent years. When asked to report any change between 2004 and 2007,

Table 4.4   Ranking of individual channels of UILs as moderately or very important by Chinese firms

Rank	UIL channel that contributed to firm innovation (moderately important or very important)	%
1	Joint or cooperative R&D projects	63.9
2	Licensed technology	58.9
3	Patents	57.6
4	Contractual research	52.6
4	Consultation with individual researchers	52.6
4	Recently hired graduates with above-Master's degree	52.6
7	Science and/or technology parks	46.7
8	Publication and reports	43.0
9	Temporary personnel exchanges	39.7
10	Informal information exchange	39.1
11	Public conferences and meetings	36.4
12	Incubators	36.1
13	Participation in networks that involve universities	31.8

127 out of the 203 professors (62.6%) said that UILs in their universities had been strengthened. Only five professors thought they had been weakened during the same period.

We looked at the specific channels of UILs that were preferred by Chinese firms and university professors (Tables 4.4 and 4.5). Table 4.4 presents the individual channels of UILs in order of the number of respondent firms that evaluated the respective channel as moderately important or very important for the firms' innovation. Chinese firms regard joint or cooperative R&D projects, licensed technology, and patents as effective channels of UILs.

The channels can be bisected in several ways: formal versus informal; contract-based versus non-contract-based; private (proprietary) versus public (open science); and direct versus indirect. Chinese firms seem to prefer the formal, contract-based, private (proprietary), and direct channels.

Despite its somewhat different design, the professor survey also verified a preference for formal contract-based channels of UILs. In the professor survey, collaborative or trusted research under formal contracts with industries was most preferred by Chinese universities (Table 4.5).

Our survey results are in sharp contrast to the results obtained by Cohen et al. (2002) in their case study in the US, where public (open science), informal, indirect, and personal channels were preferred to

Table 4.5   Ranking of individual channels of UILs as moderately or very important by Chinese professors

Rank	UIL channel (moderately important or very important)	%
1	Collaborative or trusted research under formal contracts with industries	35.5
2	Non-periodic consultation, on-site supervision, lecture, and other activities for industry	14.7
3	Student internships to industries	13.1
4	Participation and discussion in industry-related conferences and seminars	10.9
5	Sharing of research facilities and equipment between universities and industries	9.3
6	Cooperative research with a company researcher leading to the publication of articles or registration of intellectual property, all without a formal contract with the company	5.8
7	On-campus training for industry personnel	4.8
8	Consultation, supervision, and other activities for companies as official consultants	4.2
9	Your own participation in industries as the director or staff	1.0
10	Creation of your own start-up company	1.0

formal contract-based channels.[10] The channels most highly regarded by Chinese firms were placed at the bottom of the US list. Likewise, the top three channels in the US list (i.e., publications and reports, informal interacting, and meeting and conferences) were lowest on the Chinese list (Table 4.6).

To further clarify the underlying reasons for the China–US difference, we conducted follow-up interviews with five senior engineers and technology intermediaries from Chinese firms during April and May 2008. Long telephone interviews (40 minutes) with each person provided hints about the underlying reason why formal and contract-based channels are preferred in contemporary China.

A senior engineer in a shipbuilding company located in Shanghai argued that Chinese firms have only "limited absorptive capacity" and therefore they prefer to have formal contracts to make sure the transfer of target technologies is actually completed. Unbound and loose interactions with university professors, he thought, could not guarantee technology transfer. His view was shared by others, including a vice director of the Beijing Biomedical Industry Support Center.

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[10] The shares of positive answers were generally lower in the US case.

Table 4.6   Evaluation of individual channels of UILs by firms in the US

Rank	UIL channel that contributed to firm innovation (at least moderately important)	%
1	Publications and reports	41.2
2	Informal interaction	35.6
3	Meeting or conference	35.1
4	Consulting	31.8
5	Contract research	20.9
6	Recent hires	19.6
7	Cooperatives and joint ventures	17.9
8	Patents	17.5
9	Licences	9.5
10	Personal exchange	5.8

Source: Excerpt from Table 6 in Cohen et al. (2002, p. 15).

A senior engineer from a technology intermediary argued that "lack of trust" was the main reason why Chinese firms preferred formal contract-based UIL channels. In a similar vein, a senior engineer in an automotive company said that a lack of mutual trust caused by limited experience with university–industry collaboration induced both Chinese universities and firms to stick to formal contracts to protect their own interests and to prevent "opportunistic behaviours" of their partners.

Another interviewee pointed out that Chinese firms might resort to formal contracts because they are "not genuinely self-motivated" to assimilate new scientific knowledge from universities or to improve their technological capabilities from a long-term perspective. They are only interested in the safe completion of short-term projects, for which technological solutions are simply outsourced to university laboratories. In addition, a couple of senior engineers agreed that the Chinese government currently encourages formal contracts as a useful means of facilitating UILs, which is still at an early stage of development, and that the Chinese firms are simply responding to the government guidance.

In the future, China may use more diverse channels of UILs, including informal and public (or open science) channels when some prerequisites are satisfied. The prerequisites might include: increased levels of absorptive capacity and stronger incentives to pursue innovation by firms; mutual trust between universities and industries nurtured through accumulation of successful experiences in university–industry collaboration; and an institutional infrastructure that would prevent opportunistic behaviour.

Relative Importance of Universities as a Knowledge Source for Chinese Firms

There has been a gradual shift in Chinese UILs toward more horizontally networked links. However, both Chinese universities and firms still prefer formal contract-based channels when making links with each other. This preference for formal contracts is a salient feature of current Chinese UILs.

Moving away from details about UILs in China, we look at various sources of knowledge for firms and examine the relative importance of Chinese universities as a knowledge source for Chinese firms. In theory, firms can acquire innovative knowledge from both internal and external sources. There are many external knowledge sources. Firms can turn to upstream knowledge sources such as universities and research institutes that generate new knowledge through scientific research and to downstream knowledge sources such as customers. In addition, firms can learn from other firms that may be either their competitors or suppliers of intermediate goods (von Hippel 1988; Lundvall 2010). This is in line with the widely acknowledged criticism of the so-called linear model of innovation (Kline and Rosenberg 1986). Taking this into account, we tried to assess how Chinese universities stood relative to other sources of knowledge for Chinese firms.

The survey results show that universities are now playing only a very limited role as knowledge sources for Chinese firms, despite publicly reiterated emphases on their importance and potentials. Universities rank lower than many other knowledge sources, such as customers, competitors, and suppliers. Figures 4.1 and 4.2 show the percentage of respondent firms that use different knowledge sources when launching new projects and completing existing ones.

Customers are the most important knowledge sources for Chinese firms, whether they are launching new projects or completing existing projects. This indicates that demand (or market) is the most important driving force of innovation in contemporary China.

Internal sources (i.e., the firm's knowledge systems and manufacturing operations) were the second most important knowledge source for both launching and completing projects. This indicates that some Chinese firms have built up a sort of in-house knowledge management system, and that they actively assimilate and use the knowledge they generate when doing business. This also indicates that Chinese firms are no longer "branch plants" that narrowly specialize in manufacturing as dictated by the central planning board (Naugthon 1997). Firms have evolved to become strategic entities that pursue innovation to survive in a competitive market.

Customers	89.4%
The firm's knowledge systems	81.8%
Internet	70.9%
Competitors	70.5%
Cooperative or joint venture partners	68.2%
The firm's manufacturing operations	67.6%
Affiliated suppliers	62.3%
Fairs and expositions	59.3%
Technical publications and reports	56.0%
Universities	56.0%
Consulting or contracting R&D firms	54.3%
Independent suppliers	53.3%
Public research institutes (PRIs)	51.3%

Figure 4.1   Knowledge sources used by firms when launching new projects

Chinese firms also use the Internet as an important knowledge source (Figures 4.1 and 4.2). Furthermore, when firms were asked about their most important knowledge source, the Internet was cited not only as a supplement but as a main tool for firms to absorb useful knowledge from the outside world (Table 4.7).

Universities are near the bottom of frequently used knowledge sources by Chinese firms (Figures 4.1 and 4.2), although a few Chinese firms attach more importance to universities for knowledge about product and process innovations (Table 4.7). Even in advanced countries, universities are rarely the most frequently used knowledge sources for industrial firms (Cohen et al. 2002). Although there may be scientific ideas with commercial potential in universities, to many businesses these embryonic ideas are still far away from making profits. However, the underutilization of universities as knowledge sources in China might be further exacerbated by the fact that various types of UILs' channels, other than formal contract-based ones, are not fully developed.

Although few, Chinese firms that actively use universities as their
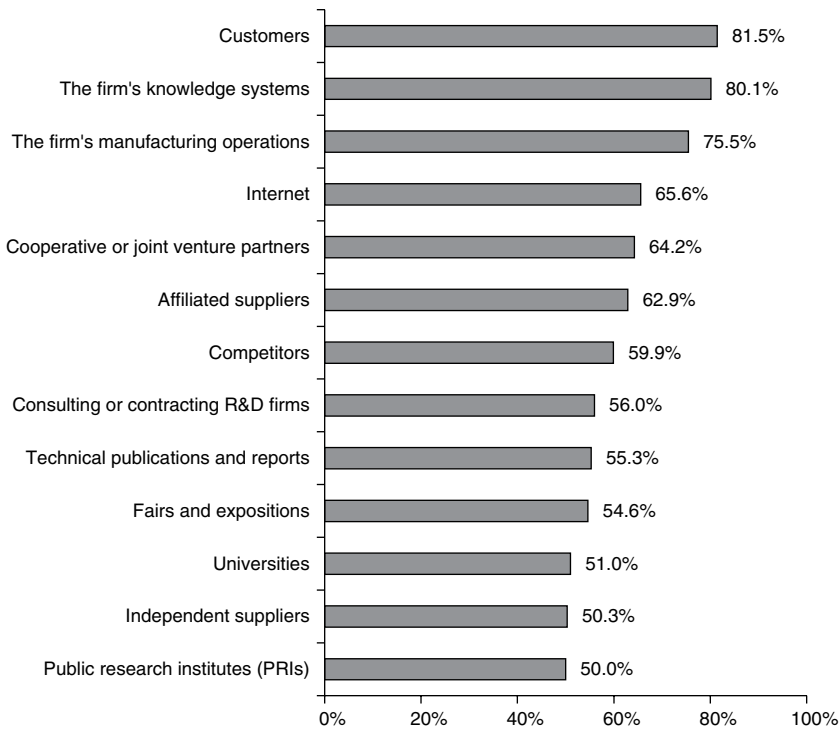
Figure 4.2 Knowledge sources used by firms when completing existing projects

knowledge source deserve further inquiry. We examined the types of firms that were more active in exploiting UILs in China. We wondered whether the degree of exploiting UILs would differ across different groups of firms in terms of ownership type (public or private firms), location (eastern area or inland area), and newness (start-up or mature firms). We conducted a series of Mann–Whitney U tests for this analysis. The Mann–Whitney U test is a non-parametric test to assess whether two samples of observations come from the same distribution.

Public enterprises (including state-owned and collective enterprises) more actively exploit links with universities. Mean ratings for public enterprises were larger than ratings for private enterprises both for launching new projects and completing existing projects, and the differences were statistically significant (Table 4.8).

Table 4.8 shows that firms located in the Midwest inland area were more active in exploiting links with universities, at least for launching

Table 4.7   Knowledge sources that were the most important for 301 Chinese firms when launching new projects or completing existing ones

Launching new projects			Completing existing projects		
Rank	Source	No. (%)	Rank	Source	No. (%)
1	Customers	121 (40.2)	1	Customers	94 (31.2)
2	The firm's knowledge systems	32 (10.6)	2	The firm's knowledge systems	52 (17.3)
3	The firm's manufacturing operations	27 (9.0)	3	The firm's manufacturing operations	37 (12.3)
4	Internet	26 (8.6)	4	Cooperative or joint venture partners	28 (9.3)
5	Cooperative or joint venture partners	19 (6.3)	5	Internet	25 (8.3)
6	Universities	18 (6.0)	6	Public research institutes (PRIs)	19 (6.3)
7	Competitors	15 (5.0)	7	Universities	11 (3.7)
8	Public research institutes (PRIs)	11 (3.7)	8	Affiliated suppliers	8 (2.7)
9	Fairs and expositions	9 (3.0)	8	Technical publications and reports	8 (2.7)
10	Affiliated suppliers	8 (2.7)	10	Competitors	7 (2.3)
11	Consulting or contracting R&D firms	5 (1.7)	11	Consulting or contracting R&D firms	5 (1.7)
11	Technical publications and reports	5 (1.7)	11	Fairs and expositions	5 (1.7)
13	Independent suppliers	3 (1.0)	13	Independent suppliers	2 (0.7)

Table 4.8   *Types of firms most active in exploiting UILs (Mann–Whitney U tests)*

Firm characteristics		Mean rating of UIL use	
		Launching new project	Completing existing project
Ownership type	Public	162.7	173.2
	Difference	v*	v***
	Private	145.9	140.6
Location	Eastern area	147.1	149.3
	Difference	^*	Not significant
	Inland area	165.6	158.4
Newness	Start-up	142.5	129.7
	Difference	Not significant	^**
	Mature	153.4	156.0

Note: Significance: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

new projects. We think that the poor availability of alternative knowledge sources (e.g., customers, competitors, and suppliers) might make these firms in the inner regions more heavily dependent on academic institutions, especially for acquiring information to launch new projects.

Contrary to our expectation, Chinese start-up firms, defined as being younger than five years old, do not actively use UILs for their innovative activities. The frequency with which start-up firms use universities to complete existing projects is significantly lower than the frequency of mature firms. This may be because many young Chinese firms are not high-tech ventures rooted in the new scientific knowledge generated in universities. Also, large and mature state-owned enterprises may well be in a better position than small and young private enterprises (including start-up firms) to exploit universities, most of which are public institutions in China.[11] This implies that Chinese universities have room to improve in terms of their accessibility to small and young companies that are searching for innovative ideas.

Forging Links with Different Types of Universities

The usefulness of universities as knowledge sources for Chinese firms varies across different groups of firms. However, these differences in UILs

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[11] Wu (2010) found that state-owned enterprises accounted for about half of the total technology contracts that firms signed with Chinese universities during 2000–2006.

might not only be caused by firm factors but by university factors. OECD (2002) pointed out that the degree and form of UILs would not be uniform across different firms and different universities.

There are differences among Chinese universities. Officially, Chinese universities are classified into two broad groups: national key universities (*zhongdian daxue*), which are normally equipped with better-quality resources for research and education; and other universities. We checked whether Chinese firms had any preference for national key universities. When doing so, we took into account geographic distance as another potential determinant for Chinese firms choosing academic partners.

National key universities located in the same province as the firm were ranked first (62.9% of the respondent firms evaluate them as at least moderately important). The second most preferred universities were national key universities located in other provinces (56.3%). Comparatively, the other universities were not recognized as important knowledge sources even when located in the same province (37.4%) or in other provinces (34.1%). Universities in other countries were ranked at 37.4%. This indicates that Chinese firms want to link with universities that have abundant quality resources rather than with universities simply near at hand. We also examined the types of Chinese firms that were more likely to forge links with each category of university. Mann–Whitney U tests show that public enterprises in China were significantly more likely to make links with key universities in other provinces than private enterprises; however, they were less likely to exploit foreign universities than private enterprises (Table 4.9). This implies that state-owned enterprises (SOEs) in China have a broader nationwide network than private enterprises, but that this network is largely limited to national universities. In addition, start-up companies and firms located in the eastern developed provinces more actively exploit foreign universities, indicating their stronger pursuit of state-of-the-art technologies developed in foreign universities (Table 4.9). Many young Chinese scientists have trained abroad, and have returned to China (especially to the eastern provinces) to establish start-up firms. They naturally have more connections with the foreign universities where they studied.

Prospects and Limits of Current UILs in China

Despite the limited importance of universities as a knowledge source for Chinese firms, our survey findings show that most Chinese firms evaluate their own experiences of collaboration with universities very positively. The survey results show that the majority of firms (146 of 156 firms, i.e., 93.6%) have already reached their pre-set goals in their partnership with

Table 4.9 Types of UILs most likely to be formed by different types of partners (Mann–Whitney U tests)

Types of universities	Public versus private firms				Eastern versus Midwest firms				Start-up versus mature firms			
	Types of firms	N	Mean rating	Diff.	Types of firms	N	Mean rating	Diff.	Types of firms	N	Mean rating	Diff.
Key universities same province	Private	201	149.00	NS	Midwest	72	158.05	NS	Mature	249	152.01	NS
	Public	100	155.03		Eastern	229	148.78		Start-up	52	146.15	
Key universities other provinces	Private	201	143.58	^**	Midwest	72	156.06	NS	Mature	249	152.25	NS
	Public	100	165.92		Eastern	229	149.41		Start-up	52	145.01	
Ordinary universities same province	Private	201	149.53	NS	Midwest	72	164.81	NS	Mature	249	151.29	NS
	Public	100	153.96		Eastern	229	146.66		Start-up	52	149.62	
Ordinary universities other provinces	Private	201	147.74	NS	Midwest	72	164.83	NS	Mature	249	150.72	NS
	Public	100	157.56		Eastern	229	146.65		Start-up	52	152.32	
Universities in foreign countries	Private	201	157.37	v**	Midwest	71	131.55	^**	Mature	248	144.78	^***
	Public	99	136.55		Eastern	229	156.38		Start-up	52	177.77	

Note: N number; NS not significant; Diff. difference; and significance ** $p < 0.05$.

Table 4.10   Factor analysis of UIL channels in China

Individual channel	Factor loading	
	Factor 1	Factor 2
Incubators	0.748*	0.221
Contractual research	0.745*	0.232
Joint or cooperative R&D projects	0.730*	0.233
Science and technology parks	0.724*	0.228
Temporary personnel exchanges	0.715*	0.232
Participation in networks that involve universities	0.694*	0.278
Recently hired graduates with above-Master's degrees	0.473	0.405
Consultation with individual researchers	0.439	0.480
Patents	0.404	0.582
Licensed technology	0.388	0.584
Publication and reports	0.262	0.757*
Public conferences and meetings	0.211	0.781*
Informal information exchange	0.103	0.758*
Eigenvalue	5.971	1.220

Note: The threshold for factor loading was 0.600.

universities, or expect to do so in the near future. Fewer than 7% of the firms stated that their collaboration with universities had already failed or would eventually fail. This indicates that Chinese firms are currently accumulating positive experiences from interacting with universities. This should lead Chinese firms to be more confident in interacting with universities and enhance trust between firms and universities. Enhanced trust would further facilitate UILs by making informal and non-contract based UIL channels more available.

In fact, Chinese firms seem to have already begun to use other types of UIL channels as a supplement to formal contract-based channels. To see how Chinese firms combine (or mix) individual channels to forge links with universities, we applied factor analysis to the evaluations firms made of the usefulness of individual UIL channels.[12] Through this factor analysis, we determined how different channels related to each another.

Table 4.10 shows that somewhat informal, personal, and network-based channels (i.e., science and technology parks, temporary personnel

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[12] Factor analysis is a statistical method used to describe variability among observed variables in terms of fewer unobserved variables called "factors."

Table 4.11   Difficulties (moderate or very relevant) with UILs as perceived by professors (using multiple choice questionnaires)

Rank	Perceived obstacles (number of respondents: 160)	Number (%) (moderately or very relevant)
1	Restriction on research time due to conflicting schedule with the industry	70 (43.8)
2	Time restriction that results from confounding existing research and education with additional industrial involvement	62 (38.8)
3	The industry's lack of understanding of the technology or the information involved	44 (27.5)
4	The university's insufficient reward system	16 (10.0)
5	The government's excessive regulations or inappropriate policies or laws	15 (9.4)
6	The industry's prejudice against the university researcher	13 (8.1)
7	Excessive regulations from the university	11 (6.9)
8	Unsatisfactory reward for the research results and unreasonable distribution of profits	10 (6.3)
9	Decrease in reputation and activities within the academic community	4 (2.5)
10	Negative opinions of fellow researchers or students within the university	3 (1.9)
11	Problems regarding co-authorship of the article	2 (1.3)

exchanges, and participation in networks that involve universities) were loaded together in the first factor with the formal contract-based channels (i.e., contractual research with universities and joint or cooperative R&D projects).[13] This implies that Chinese firms often combine the use of formal contract-based channels with efforts to construct general networks with universities. In future, the heavy dependence of Chinese UILs on narrow formal contracts could possibly be further diluted by increased use of network-based channels. However, future progress in Chinese UILs will face difficulties. Chinese professors emphasized several problems and side effects concerning burgeoning UILs in China. Table 4.11 illustrates the difficulties perceived by Chinese professors when they collaborate with firms.

[13] Publication and reports, public conferences and meetings, and informal information exchange, which represented the public (or open science) and informal channels of UIL, were loaded on the second factor.

Chinese professors perceive time restrictions as the most serious problem (Table 4.11). This indicates that professors have difficulties in meeting (from their point of view) impatient requests by industrial partners who are most likely pressed for time. This might be interpreted as a cultural difference between relatively liberal universities and tightly disciplined firms. However, it can also be attributed to the fact that professors, who are mostly tied up with teaching and academic research, have only limited time to devote to collaboration with industrial firms. This implies that there is a trade-off between education and academic research, and collaboration with industrial firms.

In addition to time restriction, Chinese professors complained that industrial partners lack understanding of technology, that there were insufficient reward systems at the universities, and that there were excessive university and government regulations (see Table 4.11). This suggests that enhanced technological capacity (or absorptive capacity) of industrial partners, improved incentive arrangements in university, and more flexible governance systems could encourage Chinese professors to participate in UILs.

Policymakers should be aware that the quality of education and academic research at universities may deteriorate when professors allocate excessive time and commitment to making direct links with industrial firms. Even firms, as the demand side of the knowledge, talents, and related service provided by universities, do not always attach the greatest importance to the active engagement of universities in industrializing S&T knowledge. Our survey of 302 firms showed that firms place top priority on the role of universities in education and training (72.5%). Firms also believe that the role universities play in industrializing S&T knowledge (71.9%) is important for them, but they ranked this particular function below the traditional role of universities, i.e., education and training. Academic research (65.9%) and social services (55.3%) conducted by universities were not highly ranked by our respondent firms.

SUMMARY AND CONCLUSIONS

Before the reform and open door policy initiated in 1978, Chinese universities and industrial firms had been largely insulated from each other within the Socialist division of labour. However, even in the pre-Reform era, Chinese universities intermittently engaged in real-world production through their own affiliated firms and farms. In the post-Reform period, when marketization and decentralization were pushed further forward and greater autonomy was given to individual actors, Chinese universities could more actively exploit market opportunities by setting up their own

business enterprises (i.e., UREs). These UREs acquired a competitive advantage because of their exclusive or at least preferential relationship with their universities. Ordinary Chinese firms had a more difficult time absorbing and exploiting new knowledge from universities due to their weak absorptive capacity and other institutional hurdles. As a consequence, UREs became a major channel of knowledge industrialization in high-tech sectors during the 1980s and 1990s. In other words, the dominant UILs by the late 1990s were the closed and vertical links between universities and their affiliated firms, whereas open and horizontal links involving ordinary firms were largely underdeveloped.

However, as the absorptive capacity of ordinary Chinese firms has improved, Chinese universities have become engaged in more commercial activities, and institutional arrangements have deepened, vertical channels of knowledge industrialization (UREs) have gradually declined. Instead, more horizontal UILs have emerged in China. These historical changes remind us that, although excessively strong, vertical, and closed links facilitated the growth of beneficiary firms (i.e., UREs), these links were socially expensive and not sustainable in the long run.

The main purpose of this study was to explore the emerging horizontal UILs in China and to discover their Chinese characteristics. We departed from the notion that there are various alternative channels to choose in horizontal UILs and explored country-specific conditions. We found that China's current horizontal UILs were characterized by heavy dependence on formal and contract-based channels. This was particularly interesting because it was just the opposite of findings from the US, where public, personal, and informal channels were more highly appreciated than formal, contract-based channels. Findings from our follow-up interviews imply that there are prerequisites for the full use of informal and public UIL channels. What China lacks among these prerequisites might include: an appropriate level of absorptive capacity and strong incentives to pursue innovation at the firm side; mutual trust between universities and industries that could be nurtured through accumulation of successful experiences in university–industry collaboration; and an institutional infrastructure that would prevent opportunistic behaviour.

Our findings might further complicate the existing debate on the most effective channels for links between universities and firms. Cohen et al. (2002) have found that informal and public channels are more important in the United States; however, this finding should not be hastily generalized as a global principle that can be applied to every country regardless of its developmental stage. Our findings show that a particular UIL channel functions well only in an adequate institutional environment.

Furthermore, successful experiences and benefits from UILs would

enhance the mutual trust between universities and firms, which makes the environment more supportive for various (beyond the one previously used) channels of UILs. This implies that the relationship between the mode of UIL in a country, and the environmental preparedness of the country, is co-evolutionary in nature.

Although Chinese UILs now heavily depend on formal contract-based channels, this lopsided dependence might gradually diminish as Chinese firms enhance their absorptive capacity and as improved institutional environments in China accommodate various UIL channels. In fact, according to our survey, Chinese firms are already using network-based channels (e.g., personal exchanges and university science parks) as a supplement to formal contract-based channels. This implies that horizontal UILs, which have recently started to replace UREs as the main channel of knowledge industrialization in China, are gradually transitioning out of their heavy dependence on formal contracts. With this two-step evolution of Chinese UILs, the Chinese NSI will also change by harnessing more horizontal networks and by gaining more openness and flexibility.

In this study, we also examined the relative importance of universities as an alternative knowledge source for Chinese firms. This revealed that Chinese firms do not highly appreciate universities as an innovative knowledge source. Customers, a typical downstream knowledge source, proved to be much more important than upstream universities. Thus, one should not exaggerate the function of universities as an innovative knowledge transmitter in China, although their importance is rising in the so-called knowledge-based economy.

At the same time, one should be aware that universities can contribute to industry not only by transmitting disembodied knowledge through direct links with industrial firms, but indirectly by supplying well-educated graduates. According to our survey, Chinese firms attach more importance to education and training than to industrializing S&T knowledge and academic research, as a channel through which universities can contribute to firms. Furthermore, some Chinese professors experienced uncomfortable trade-offs between education and research, and collaboration with industrial firms. A policy suggestion that we can draw from this finding is that policymakers (both in universities and governments) should pay close attention to the contributions universities make to industry and society when they provide well-educated graduates. An excessive emphasis on making direct links between university and industry could be disadvantageous, not only to education and long-term academic research, but also to social welfare.

PART II

Dynamic interactions: matches and mismatches over time

5. Relevance of university–industry links for firms from developing countries: exploring different surveys

Marcelo Pinho and Ana Cristina Fernandes

The impressive growth of the literature on National Systems of Innovation (NSIs) since the 1990s reflects the approach's current influence on dealing with the innovation and economic performance of countries and regions (Fagerberg and Sapprasert 2011). An NSI[1] approach includes universities and public research institutes (PRIs) as one set of crucial constituent organizations. Nevertheless, conceptualization of the actual role they play within innovation systems, as Mowery and Sampat (2005) point out, is still controversial and varies considerably over time, across industrial sectors and countries, and among academic experts and policymakers.

Since the 1970s, when declines in public research funding affected universities in many Organisation for Economic Co-operation and Development (OECD) countries and the costs of industrial research soared (Nelson and Rosenberg 1993), the role of universities and PRIs in NSIs has come into focus in innovation studies. The call is for more investigation and empirical accounts of the knowledge flows between academic organizations and firms, both in developed and developing countries. As innovation outputs underpin the growth of a national or regional product, a more accurate understanding of the role of universities and PRIs should inform the policymaker. As urged by Mowery and Rosenberg (1982, pp. 237–238):

> intelligent policies must be directed at institutional aspects of the innovation process, working to encourage the interaction of users and producers, as well as the interactions between more basic and applied research enterprises . . .

[1] For Metcalfe (1995, pp. 462–463), NSIs are ". . . that set of distinct institutions which jointly and individually contribute to the development and diffusion of new technologies and which provides the framework within which governments form and implement policies to influence the innovation process. As such it is a system of interconnected institutions to create, store and transfer the knowledge, skills and artifacts which define new technologies."

> Useful policies would be those directed at the provision of information, from basic research institutions in the noncommercial sector to private firms and laboratories, as well as from users to producers concerning desired products and characteristics.

In this context, key contributions have shed light on critical aspects of the collaboration between university and industry, among them the Yale and Carnegie Mellon (CM) surveys (Levin et al. 1987; Cohen et al. 2002). Despite being focused on the US, these studies elucidate the issue in more generalizable terms. Mowery et al. (2004) highlight five factors. First, the historical origins and development of a country's system of higher education, its scale, and structure greatly affect university–industry collaboration, as well as its economic formation (Rosenberg 1982; Nelson and Rosenberg 1993; Fagerberg 2005). Second, inter-industry differences show that the biomedical sector, particularly biotechnology and pharmaceuticals, is unusual with respect to university–industry collaboration because it significantly and directly relies on academic basic research as compared to other industrial sectors. Third, these studies commonly found that engineering and applied sciences ranked higher in importance for industrial innovation. Mowery and Sampat (2005) point out that the low importance of fields such as physics and mathematics indicate that these fields will affect industrial innovation after a considerable lag, as they are absorbed into applied sciences. Fourth, and very important for understanding the role of universities in NSIs, the CM study data indicate that, for most sectors, industrial R&D projects are not triggered by results of academic research but more often by inspiration stemming from customers and manufacturing operations (again, excepting pharmaceuticals). Fifth, the studies disclosed that research methods and instruments were more important academic research outputs than prototypes. Regarding information channels, "traditional" channels, such as publications and conferences, were ranked well above patents and licences by university and PRIs.

These findings have important policy implications. The relevance of universities and PRIs as actors in NSI has led to a widespread interpretation among policymakers in both developed and developing countries. They expect universities to incorporate a more "industrial" role into their traditional education and research functions. Such a role means that universities should focus on greater economic returns from their research results, and engage in strong links with other organizations within knowledge-based economies. For Mowery and Sampat (2005), however, universities are rather difficult to analyse as economic institutions because they play multiple roles in NSIs, and mirror the features of a cooperative organization more than those of a hierarchically structured economic unit.

Improved university–industry links (UILs) are likely to reflect not only transformation of the university culture, but also the needs of industries for basic knowledge and research results that universities can provide.

In developing countries, one should expect differences in the ways universities and industry collaborate. University–industry collaboration is usually recognized as rare, weak, and limited in terms of the nature of the positive feedback between the two institutional actors (Arocena and Sutz 2003). Collaboration typically involves low-level industrial innovation, concentrated on consultancy rather than on knowledge-intensive services because universities focus on basic research (Arocena and Sutz 2001). Meanwhile, industry aims to adapt and upgrade imported technology rather than undertake R&D (Bell and Pavitt 1995). In catch-up economies such as South Korea, UILs are reported mostly in terms of the supply of skilled labour (Pavitt 2001).

There is a "strong belief that the technological capabilities of a nation's firms are a key source of their competitive process, with a belief that these capabilities are in a sense national, can be built by national action" (Nelson and Rosenberg 1993, p. 3). Because of the configuration of NSIs, differences can be expected in the roles of universities and PRIs in "knowledge-based" economies as compared with developing ones. Surveys similar to the CM and Yale studies carried out in developing economies would presumably yield rather different results. The particular historical processes in developing countries would lead to differences in the role of universities and PRIs in "immature" NSIs (Albuquerque 1999) and in the sources and channels of information for innovation used by firms.

This chapter contributes to this debate by gathering and summarizing and analysing evidence from developing countries. Specifically, it addresses three basic issues concerning the relationships that connect industry, universities, and PRIs in the NSIs of these countries: (1) the degree of success of this relationship; (2) the main modes of relationship between universities, PRIs, and firms; and (3) the ranking of universities and PRIs among the sources of information for innovation projects.

THE DATA SET

This chapter draws on the surveys carried out in the countries covered by the research project discussed in the Introduction to this book. Besides representing 48% of the world population, these 12 countries[2] jointly account for 30% of global gross domestic product (GDP) (in terms of

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[2] Data for 2010 derived from IMF (2011).

purchasing power parity). These shares are largely due to China and India, the world's most populated countries, but the remaining ten countries in our sample contribute about one third to that share of the world's GDP, and two out of nine in the case of inhabitants.

Although inspired by a common purpose, each national survey was carried out independently and affected by specific contingencies. Likewise, elaboration of country reports and papers was not driven by stringent guidelines. Therefore, the availability of data varies on a case-by-case basis. For example, because we relied mostly on information published in reports and papers,[3] we were not able to gather data about the issues addressed in this chapter for the two lowest income countries (Uganda and Nigeria). For the other countries, we have data on at least some of the issues, but not necessarily on them all.

The main characteristics of the sets of firms surveyed in each country are shown in Table 5.1. To be compared, the country studies' results should be methodologically compatible. Although the common origin of the studies induces compatibility, this is not assured.

Table 5.1 shows samples of similar size, ranging from 300 to 600 firms. Table 5.1 also shows that, following the tradition of innovation surveys, the studies focused on innovative firms rather than on "representative" ones. In Thailand, South Africa, and Mexico, every firm was considered innovative according to the Oslo Manual criteria (OECD 2005). This is the broadest definition of innovation – all firms that introduced products or processes that were new to them. In India, Costa Rica, and Brazil, the figures are slightly lower, but more than 90% of the firms were considered innovative. For Malaysia, firm innovation was not reported. However, a similar pattern is likely because of industry-selection bias: only firms from the electronics, biotechnology, and automotive sectors were included. In Argentina, the survey returned a lower ratio of innovative firms, but no less than two thirds of the firms were innovative. Although information for China and South Korea is lacking, it does not mean that their surveys were different in this aspect. We could not find in the reports and papers an accurate description of the ratio of innovative firms to the total number of firms surveyed, but it is likely that the firms in the samples are no less innovative.

Sectoral biases seem unlikely in most countries, except Malaysia and India, but in the latter case to a much lesser extent (Table 5.1). The set of Brazilian firms interviewed is affected by another kind of bias: the

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[3] Besides Brazil, the exceptions are India and Mexico, where we had wide access to survey data. We gratefully thank Valeria Arza, Gabriela Dutrénit, and K.J. Joseph for providing unpublished data.

Table 5.1   Description of the sets of firms in each of the country surveys

Country	Number of firms	Characteristics of the survey and the samples
South Korea	600	Firms covered in the Korean National Innovation Survey
India	462	94% of firms were considered innovative; 86% performed research and development (R&D); 50% of firms with R&D intensity > 5%; 79% from five sectors: (1) chemical (including pharmaceuticals and biotechnology), (2) automotive, (3) IT and electronics, (4) machine tools, and (5) textile and garments
China	302	12.2% response rate in a sample of 2484 firms originated from three lists: (1) 2006 yearbook of largest manufacturing firms; (2) firms members of private science and technology (S&T) entrepreneurs network; and (3) firms registered to China Small- and Medium-size Enterprise (SME) online
Malaysia	361	Firms in three industries: automotive, biotechnology, and electronics
Thailand	≈ 350	Innovation Survey (2003): 5.8% of 6031 sampled firms had introduced innovations; results shown are from innovative firms only
South Africa	506	Innovation Survey (2004): 52% of 979 interviewed firms were rated innovative; results shown are from innovative firms only
Argentina	354	Innovation Survey (2006) Annex: 354 linked firms (another 238 non-linked firms in the control group); 67% of them were regarded as innovative
Costa Rica	376	Innovation Survey (2006–2007) Annex: 94% of firms had introduced innovations in the past three years
Mexico	341	All innovative firms (non-innovative firms excluded) sampled from a list where nearly 70% benefited from R&D fostered by public funds
Brazil	324	97% of total considered as innovative firms; 96% of them regarded as R&D performing firms; sample comprises innovative firms only

Sources: Arza and López (2008); Arza (2009); Dutrénit and De Fuentes (2009); Kruss (2009b); Lee et al. (2009); Orozco and Ruiz (2009, 2010); Dutrénit and Arza (2010); Dutrénit et al. (2010b); Fernandes et al. (2010); and Pinho (2011).

universe of targeted companies comprised only firms with which academic researchers have previously declared some kind of partnership. Four studies (Thailand, South Africa, Argentina, and Costa Rica) were directly based on national innovation surveys, some with extended questionnaires. Although statistical representativeness is not assured in other countries, we could not identify other significant biases. Provided the necessary caution, we do not believe that the biases hinder comparisons.

DEGREE OF SUCCESS OF UILs

Figure 5.1 exhibits an evaluation of the degree of success of UILs from the viewpoint of firms in eight countries where this information is available. Firms were asked whether their relationship with academic institutions (universities and PRIs) had met their objectives. Because relevant projects might not have been concluded at the time of the survey, firms were prompted to alternative responses in terms of expected results.

Results are quite similar and depict a stimulating picture. The country with the least positive evaluation of success was South Korea, a country
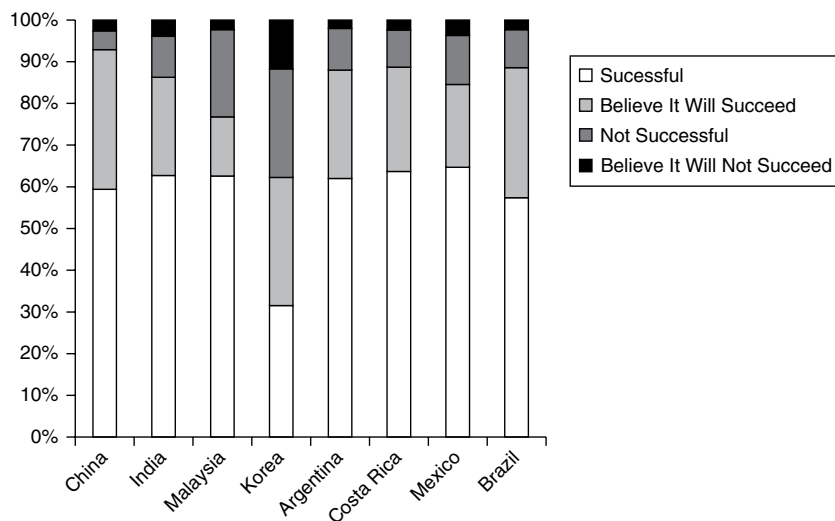
Sources: Arza and López (2008); Arza (2009); Dutrénit and De Fuentes (2009); Kruss (2009b); Lee et al. (2009); Orozco and Ruiz (2009, 2010); Dutrénit and Arza (2010); Dutrénit et al. (2010b); Fernandes et al. (2010); and Pinho (2011).

Figure 5.1   Degree of success of UILs as evaluated by firms

that managed to develop furthest toward catching up. In Malaysia, summing up the ongoing relationships and those already concluded, we found a 77% rate of success. For all other countries, success was realized or forecasted by 85% or more of the respondents.

In fact, the figures are so high that they are a little hard to accept. One might suspect a respondent bias: firms willing to answer a questionnaire posed by academic researchers about links with academic institutions are likely to be more frequently those who have benefited from these relationships. Nevertheless, we did not find a lower rate of satisfied firms in Argentina and Costa Rica, the two countries where the information originated from a national innovation survey, and was thus presumably free of respondent bias.

Another interesting issue is how the degree of success is associated with technological intensity. The sectoral breakdown of the Brazilian data showed that the degree of success was, to a certain extent, negatively related to technological intensity. The overall success rate was 89%, but for high-tech manufacturing, information and communications technology, and engineering and R&D firms success was reported by fewer firms: 82%, 80%, and 80%, respectively (Pinho 2011). Unfortunately, we did not find comparable data for other countries, except for Malaysia. The Malaysian data, however, yielded higher rates of successful relationships in biotechnology (95%) and electronics (81%) than in the automobile industry (42%) (Lee et al. 2009, p. 86).

SOURCES OF INFORMATION FOR TECHNOLOGICAL INNOVATION

The issue of sources of information for technological innovation requires more detailed examination. First, we address the relative position of universities and PRIs in the ranking of information sources. Second, we ask if the national rankings are similar. In this section, data availability is particularly critical. For some countries, we have data on sources of information for suggesting new projects and for completing existing ones. However, in some countries there is information on only one of these subjects, and in some countries the distinction was not considered at all. As we will argue, for one of our purposes it is useful to combine these three sources.

Tables 5.2 and 5.3 show the primary data the project generated. Following the procedure adopted in the CM survey, two questions were asked: one regarding sources of information for suggesting new projects; and the other referring to completion of existing projects. To provide a point of comparison from an advanced economy, we included data from

the original CM survey on US manufacturing firms that perform R&D (Cohen et al. 2002).

   Before analysing the data, we must highlight two problems that hamper international comparisons. Figures marked in italics are not fully comparable to those from other countries. For example, in the Brazilian survey, firms were not asked about "affiliated suppliers" but rather about other firms in general. In China, "indigenous knowledge system" was conceived to be "firm's knowledge systems" (Lee et al. 2009, p. 55). As well, figures

Table 5.2   Sources of information used by firms when suggesting new projects

Sources	India		China		Malaysia		Mexico		Brazil		USA	
	%	R	%	R	%	R	%	R	%	R	%	R
Firms' own manufacturing process	81.0	1	67.6	6	86.7	1	48.8	4	71.6	1	73.7	2
Customers	71.7	2	89.4	1	70.9	3	64.3	1	68.2	2	90.4	1
Public research institutes	17.0	12	51.3	13	37.1	12	27.4	9	46.6	8	na	na
Independent suppliers	41.4	6	53.3	12	46.3	9	40.1	6	40.1	10	45.6	4
Technical publications and reports	50.8	4	56.0	9	61.8	5	43.7	5	49.7	6	na	na
Affiliated suppliers	38.1	7	62.3	7	80.3	2	25.3	11	*50.3*	*5*	na	na
Universities	14.4	13	56.0	9	34.1	13	27.9	8	57.4	3	*31.6*	*6*
Competitors	33.3	8	70.5	4	54.0	7	34.1	7	36.7	11	40.5	5
Internet	55.1	3	70.9	3	62.0	4	57.1	2	47.8	7	na	na
Consulting or contract R&D firms	24.0	11	54.3	11	57.1	6	19.6	12	24.1	12	22.8	7
Fairs and expositions	28.5	10	59.3	8	42.4	10	52.5	3	53.1	4	na	na
Indigenous knowledge systems	50.8	4	*81.8*	*2*	41.3	11	na	na	40.7	9	na	na
Cooperative or joint venture with other firms	28.8	9	68.2	5	53.5	8	27.4	9	24.1	12	49.6	3

Note: R = rank; na = data not available; numbers in italics are not fully comparable to data from other countries.

Sources: Cohen et al. (2002); Dutrénit and De Fuentes (2009); Lee et al. (2009); Dutrénit et al. (2010b); and Pinho (2011).

Table 5.3   Sources of information used by firms when completing projects

Sources	India		China		Malaysia		Mexico		Brazil		USA	
	%	R	%	R	%	R	%	R	%	R	%	R
Firms' own manufacturing process	74.1	1	75.5	3	60.9	2	48.6	2	74.7	1	78.2	1
Customers	60.1	2	81.5	1	44.0	5	53.0	1	56.5	3	59.1	3
Public research institutes	16.8	12	50.0	13	34.1	9	24.5	9	54.9	4	na	na
Independent suppliers	33.8	6	50.3	12	43.2	6	34.9	6	45.4	9	60.6	2
Technical publications and reports	40.5	5	55.3	9	51.0	4	35.7	5	50.3	5	na	na
Affiliated suppliers	32.5	7	62.9	6	70.6	1	22.2	10	*47.2*	*8*	na	na
Universities	12.4	13	51.0	11	30.7	12	26.1	7	59.6	2	*36.3*	*5*
Competitors	26.1	8	59.9	7	33.5	10	25.1	8	34.3	11	11.7	7
Internet	46.0	3	65.6	4	55.4	3	48.3	3	48.8	7	na	na
Consulting or contract R&D firms	19.4	11	56.0	8	38.5	7	16.5	12	28.7	12	34.2	6
Fairs and expositions	20.9	10	54.6	10	29.6	13	40.6	4	50.0	6	na	na
Indigenous knowledge systems	40.7	4	*80.1*	*2*	32.1	11	na	na	42.0	10	na	na
Cooperative or joint ventures with other firms	21.8	9	64.2	5	37.1	8	21.7	11	25.0	13	47.2	4

Note: R = rank; na = data not available; numbers in italics are not fully comparable to data from other countries.

Sources: Cohen et al. (2002); Dutrénit and De Fuentes (2009); Lee et al. (2009); Dutrénit et al. (2010b); and Pinho (2011).

published by Cohen et al. (2002) do not distinguish between universities and research institutes.

   After adjustment for this problem, Table 5.2 shows that the two main sources of information for suggesting new projects are usually the same as reported by US firms (Cohen et al. 2002): the firms' own manufacturing operations and customers. Table 5.3 indicates that there is convergence on the most-cited information sources for completing projects, although customers are usually more important in developing countries than in the

Table 5.4   Importance of universities and PRIs as sources of information for innovation by firms

Countries	Suggesting new projects				Completing projects			
	Mentioned		Most important		Mentioned		Most important	
	%	Rank	%	Rank	%	Rank	%	Rank
Universities								
India	14.4	13/13	3.2	6/13	12.4	13/13	2.5	6/13
China	56.0	9/13	6.0	6/13	51.0	11/13	3.7	7/13
Malaysia	34.1	13/13	na	na	30.7	12/13	na	na
Mexico	27.9	8/12	na	na	26.1	7/12	na	na
Brazil	57.4	3/13	13.3	3/13	59.6	2/13	13.6	3/13
USA	31.6	6/7	na	na	36.3	5/7	na	na
Public Research Institutes (PRIs)								
India	17.0	12/13	5.8	3/13	16.8	12/13	5.6	4/13
China	51.3	13/13	3.7	8/13	50.0	13/13	6.3	6/13
Malaysia	37.1	12/13	na	na	34.1	9/13	na	na
Mexico	27.4	9/12	na	na	24.5	9/12	na	na
Brazil	46.6	8/13	3.5	7/13	54.9	4/13	9.2	4/13

Notes: "Mentioned" refers to firms that identified universities and PRIs among the sources of information for innovation, whereas "Most Important" refers to firms that identified them as the single most important source.
Rank = rank among total possible number of replies; na = data not available.

Sources: Cohen et al. (2002); Dutrénit and De Fuentes (2009); Lee et al. (2009); Dutrénit et al. (2010b); and Pinho (2011).

US. This result may be associated with the roles of many of these firms as suppliers to global production networks led by assemblers or distributors. The partial exception of Malaysian sources for completing projects may be explained by the bias arising from a sample heavily affected by two (out of three) sectors dominated by transnational companies. As a consequence, the role of affiliated suppliers in Malaysia is much more prominent. Firms' own competences in manufacturing are also ranked a little lower in Mexico, but only for suggesting new projects.

Similar to results for the US (Cohen et al. 2002), universities and PRIs have a low ranking as sources of information for innovation in developing countries (Table 5.4). Rankings are lower in developing countries, mainly because the surveys prompted firms with more options (13 versus 6) for sources of information. Indeed, the percentages of firms that mentioned universities as a source of information are considerably higher, at least in

Brazil and China. In addition, the percentages for developing countries refer just to universities, whereas the figures in Cohen et al. (2002) also include "government labs."

These results might amaze at first glance, but they are consistent with data from the national innovation surveys. Pinho (2011) remarked that in the 2008 Brazilian innovation survey, 6.8% of innovative firms regarded universities as highly important sources of information, whereas, in a community innovation survey conducted by the European Union, this ratio was 4.3% (European Commission 2011). Peterson (2008, p. 10) had already pointed out that South African figures exceed the European figures.

These data call into question the common notion that in emerging countries UILs are missing or weak. There is no clear and sound evidence to support this conjecture. Nevertheless, data on the importance attributed by firms to universities as a source of information for innovation cannot be considered as evidence of stronger or more frequent relationships in developing countries. As a matter of fact, there are no data to support any of these positions.

Table 5.4 also allows a closer look at the rankings of universities and PRIs. For some countries, besides data on the role of the sources of information for innovation, irrespective of their degree of importance, we have data on the "most important source" of information. Although data are available for just three countries, it is clear that, in India and China, both kinds of institutions rank higher in terms of "most important" sources.[4] This is true both for suggesting new projects and for completing them. This result should not be underestimated. How can it be understood? One conjecture is that UILs may be somewhat unusual, but when they do occur, they are of striking importance.

Another interesting result is that for the three Asian countries, PRIs rank higher than universities as sources for completing projects. In India, PRIs are also considered more important for suggesting new projects. In Brazil, however, universities are ranked higher in all respects.

To assess the similarities among the national rankings of sources of information for innovation, we estimated the correlation coefficients among them. This procedure was hampered by the low number of countries with strictly comparable data. To tackle this problem, we built a larger table that combines information about both suggesting new projects and completing existing ones for every country for which data were available (Table 5.5). This table encompasses seven developing countries and the USA. The principle adopted in the table is quite simple: if a source is

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[4] In Brazil, this does not happen, but in every ranking, Brazilian firms attribute much more importance to universities.

Table 5.5   Sources of information used by firms for innovation

Sources	India		China		Malaysia		Mexico		Brazil		Thailand		South Africa		USA	
	%	R	%	R	%	R	%	R	%	R	Likert	R	%	R	%	R
Firms' own manufacturing process	81.0	1	75.5	3	86.7	1	48.8	4	74.7	1	3.66	2	49.3	1	78.2	2
Customers	71.7	2	89.4	1	70.9	3	64.3	1	68.2	2	3.76	1	34.5	2	90.4	1
Public research institutes	17.0	12	51.3	13	37.1	12	27.4	9	54.9	4	2.08	10	3.4	8	na	na
Independent suppliers	41.4	6	53.3	12	46.3	9	40.1	6	45.4	9	2.97	4	24.3	3	60.6	4
Technical publications and reports	50.8	4	56.0	9	61.8	5	43.7	5	50.3	7	2.69	7	3.8	7	na	na
Affiliated suppliers	38.1	7	62.9	7	80.3	2	25.3	11	50.3	6	2.68	8	na	na	na	na
Universities	14.4	13	56.0	9	34.1	13	27.9	8	59.6	3	2.03	11	5.2	5	36.3	6
Competitors	33.3	8	70.5	5	54.0	7	34.1	7	36.7	11	2.84	6	12.6	4	40.5	5
Internet	55.1	3	70.9	4	62.0	4	57.1	2	48.8	8	3.34	3	Na	na	na	na

Consulting or contract R&D firms	24.0	11	56.0	9	57.1	6	19.6	12	28.7	12	2.24	9	4.0	6	34.2	7
Fairs and expositions	28.5	10	59.3	8	42.4	10	52.5	3	53.1	5	2.85	5	na	na	na	na
Indigenous knowledge systems	50.8	4	81.8	2	41.3	11	na	na	42.0	10	na	na	na	na	na	na
Cooperative or joint venture with other firms	28.8	9	68.2	6	53.5	8	27.4	9	25.0	13	na	na	na	na	49.6	3

Notes: For the countries listed in previous tables (India, China, Malaysia, Mexico, Brazil, and US), the data are, for each source, the greater of two percentages of firms: (1) those that mentioned the source for suggesting new projects; and (2) those that mentioned the source for project completion. It is likely that some firms considered a source useful just for one of the purposes; therefore, these percentages should be seen as the lowest boundary for the real range in which actual percentage lies.

For Thailand, data are Likert-scale averages of firms' evaluation of the importance of each source of information. Answers varied from 1 (not important) to 5 (very important). Besides options more closely related to those found in other surveys, five alternative sources of information were prompted to firms: foreign-owned suppliers; professional conferences and meetings; business service providers; patent disclosures; and private non-profit research institutes. The highest ranked of them (foreign-owned suppliers) would be 7 of 16 sources of information. Data for independent suppliers and consulting or contract R&D firms come from categories defined somewhat differently: locally owned suppliers and technical service providers, respectively.

For South Africa, data are percentages of firms that assess each source of information in general as "highly important." Firms were prompted with two alternatives not found in other surveys. Professional or industrial associations ranked 5 of 10 sources of information, and conferences 6 of 10. R = rank; na = data not available; numbers in italics are not fully comparable to data from other countries.

Sources: Cohen et al. (2002); Dutrénit and De Fuentes (2009); Kruss (2009b); Lee et al. (2009); Dutrénit et al. (2010b); and Pinho (2011).

Table 5.6   Correlation matrix of sources of information used by firms for innovation

	India	China	Malaysia	Mexico	Brazil	Thailand	South Africa	USA
India	1.000	0.488	0.771	0.886	0.657	0.943	0.943	0.886
China		1.000	0.733	0.549	0.549	0.549	0.488	0.549
Malaysia			1.000	0.543	0.429	0.714	0.600	0.543
Mexico				1.000	0.771	0.943	0.943	1.000
Brazil					1.000	0.600	0.829	0.771
Thailand						1.000	0.886	0.943
South Africa							1.000	0.943
USA								1.000

Sources: Cohen et al. (2002); Dutrénit and De Fuentes (2009); Kruss (2009b); Lee et al. (2009); Dutrénit et al. (2010b); and Pinho (2011).

mentioned for at least one of the two purposes, it should be considered important for innovation in general.

There is a trade-off between: (1) larger coverage in terms of countries; and (2) consistent alternatives of information sources prompted to the interviewed firms in different countries. The most inclusive table we could build in terms of number of countries (seven developing countries and the US) led to the least comprehensive list of sources. No more than six sources were prompted as an alternative to the firms of all these countries. However, there were more similarities than divergences among the rankings. The correlation matrix (Table 5.6) shows that there is no clear evidence of greater similarities among developing countries rankings than with US rankings.[5]

CHANNELS OF INFORMATION AND MODES OF RELATIONSHIP

Table 5.7 shows the channels of information and modes of relationship through which UILs occur. The data are the percentage of firms that considered each mode of relationship with universities as at least moderately important.[6]

[5] Although Brazil is a rather unique case in this table, its ranking is likely to be affected by the bias in the firms surveyed.
[6] Options prompted to respondents were: not important; slightly important; moderately important; and very important.

Table 5.7 Channels of information between universities and firms

Channels	India %	India R	China %	China R	Malaysia %	Malaysia R	Mexico %	Mexico R	Costa Rica %	Costa Rica R	Argentina %	Argentina R	Brazil %	Brazil R	USA %	USA R
Joint or cooperative R&D projects	45.0	11	63.9	1	41.5	6	46.5	3	26.6	9	25.0	7	68.2	2	17.9	7
Licensed technology	49.4	5	58.9	2	49.3	2	30.8	10	29.0	5	16.0	8	33.0	10	9.5	9
Patents	49.4	5	57.6	3	65.1	1	33.5	9	16.9	12	15.0	9	33.0	10	17.5	8
Recently hired graduates (> Master degree)	48.5	7	52.6	4	41.0	7	48.9	1	41.1	3	27.0	4	62.7	3	19.6	6
Consulting with individual researchers	48.3	8	52.6	4	43.0	5	40.3	6	29.0	5	26.0	5	52.5	7	31.8	4
Contract research	45.5	10	52.6	4	32.2	9	37.8	7	29.0	5	26.0	5	54.3	6	20.9	5
S&T parks	51.0	4	46.7	7	21.3	12	na	Na	25.0	10	12.0	11	36.4	9	na	Na
Publications and reports	66.6	1	43.0	8	26.6	11	45.3	4	41.1	3	47.0	2	69.4	1	41.2	1
Temporary personnel exchanges	37.9	12	39.7	9	26.8	10	25.2	11	24.2	11	10.0	12	33.0	10	5.8	10
Informal information exchange	52.3	3	39.1	10	47.4	3	41.9	5	57.3	1	51.0	1	61.7	4	35.6	2
Public conferences and meetings	60.7	2	36.4	11	43.7	4	48.9	1	50.8	2	46.0	3	61.4	5	35.1	3
Incubators	37.8	13	36.1	12	20.8	13	24.3	12	15.3	14	5.0	13	21.9	13	na	Na
Participation in networks involving universities and PRIs	46.4	9	31.8	13	35.2	8	34.5	8	28.2	8	15.0	9	48.1	8	na	Na
University-run enterprises	30.4	14	na	na	10.8	14	na	na	16.1	13	3.0	14	15.4	14	na	Na
Spin-off of a university	25.9	15	na	na	9.4	15	10.8	13	13.7	15	2.0	15	na	na	na	Na

Note: R = rank; and na = data not available.

Sources: Cohen et al. (2002); Arza and López (2008); Arza (2009); Dutrénit and De Fuentes (2009); Kruss (2009b); Lee et al. (2009); Orozco and Ruiz (2009, 2010); Dutrénit et al. (2010b); and Pinho (2011).

In contrast to sources of information for innovation, there were no clearly "most important" channels for all the eight countries with available and compatible data (Table 5.7). Seven different channels were cited so frequently as to be considered first or second most important. Nevertheless, channels associated with "public science" (publications, conferences, and informal exchanges) prevailed in Latin American countries, following the pattern observed by Cohen et al. (2002) in the US. Publication and reports, which were the most important channels for UILs in the US, ranked first in Brazil and India, second in Argentina, third in Costa Rica, and fourth in Mexico. Informal exchanges and public conferences (second and third highest in the US) were among the five main channels for every developing country, except China.

Interestingly, patents and licensed technology were not among the preferred modes of relationship (with the exceptions of Malaysia and China). Following the Bayh–Dole Act in 1980, which amended patent law, numerous countries issued legislation to foster technology transfer from universities to industry. Easing the restrictions on private appropriation of innovation developed through the use of public resources was a key measure in these policies. In the US, this led to a rapid increase in patent applications by universities. Owen-Smith et al. (2002, p. 25) report a "nearly sevenfold rise" in the number of patents filed by higher education institutions during 1976–1998. Nevertheless, according to OECD (2007a, p. 12), in the mid-2000s the share of universities in the requesters of patents was not greater than 7% in the countries that pioneered such policies (USA, Canada, and Australia) and remained at even lower levels in the European Union (3%) and Japan (1.5%). The results shown in Table 5.7 for both the US and developing countries are consistent with these figures.

Table 5.8 shows a correlation matrix for modes of relationship between universities and firms. It reinforces the idea that rankings are rather similar among Latin American countries and between them and the US. In contrast, correlations with China and Malaysia are negative. Even between China and Malaysia correlation is rather weak. In this respect, India resembles Latin America and the US more closely than China and Malaysia. Indeed, in these two countries UILs seemingly mismatch the pattern observed in the other six countries, including the US. For these seven countries, correlation coefficients are not low. The exceptions should be explained individually. For Malaysia, biases in the set of surveyed firms are likely to play a role. The unusually high ratio of respondents that favoured patents as a channel of information is certainly related to the high percentage (35%) of biotechnology firms in the Malaysian survey (Lee et al. 2009, p. 73). In China, the preference for more formalized modes of relationship is well documented and mirrors institutional

Table 5.8   Correlation matrix of modes of relationship between universities and firms

	India	China	Malaysia	Mexico	Costa Rica	Argentina	Brazil	USA
India	1.000	−0.377	−0.015	0.579	0.584	0.782	0.517	0.815
China		1.000	0.398	−0.072	−0.662	−0.571	−0.167	−0.470
Malaysia			1.000	−0.047	−0.149	−0.154	−0.347	−0.097
Mexico				1.000	0.609	0.712	0.912	0.684
Costa Rica					1.000	0.893	0.628	0.692
Argentina						1.000	0.772	0.912
Brazil							1.000	0.713
USA								1.000

Sources: Arza and López (2008); Arza (2009); Cohen et al. (2002); Dutrénit and De Fuentes (2009); Kruss (2009a); Lee et al. (2009); Orozco and Ruiz (2009, 2010); Dutrénit et al. (2010b); and Pinho (2011).

characteristics of the country that hinder adoption of informal and public channels (Lee et al. 2009, p. 50; Schiller and Lee, see Chapter 2, this book).

CONCLUSIONS

Our most important point is a controversial one. There are reasons to doubt the widespread notion that relationships between universities and industry are less important to firms in developing countries, at least in those that have advanced beyond the first stages of economic development.

This notion, very rooted in common sense, is related to the clearly lower performance of developing countries both in science advancement and technical progress. Mostly due to the remarkable growth of China, the proportions of developing countries in the world's total scientific publications and R&D spending have increased. However, by 2005 they did not exceed, respectively, 19% and 18% of world figures (OECD 2009, pp. 1–3), well below their shares in GDP (38%) and population (81%).[7] Another factor that may contribute to this perception is the direct and simplistic association between universities and science. The neo-Schumpeterian school maintains that "strictly scientific knowledge" has much stronger connections with technical change in its disruptive movements (the major

[7] In all cases, the data are for non-OECD countries. Data for GDP and population are from IMF (2011). GDP was converted to dollars at "purchasing power parity" exchange rates.

advances and paradigm shifts) than in the "normal" changes that occur along technology trajectories (Dosi 1988a,c). Therefore, if one thinks of universities solely as the locus for performing science, it is hard to see a relevant space for UILs in environments that are not at the leading positions – either at the frontier of scientific knowledge or at the head of major technological innovations.

We believe that the technological demand of firms to universities in developing countries is different from that experienced in developed countries, but not necessarily weaker or less relevant. Usually, the relationship is not concerned with innovation in a strict sense, but with adaptation, improvement, incremental change, and adjustments to local conditions (Bell and Pavitt 1993).[8] We should keep in mind that the profile of technology demand is defined and constrained by the structural characteristics of technological dynamics in developing countries, but that does not mean absence of demands to universities. For the specific needs of firms in developing countries, and in an economic environment less able to meet technological demands through competences internalized in business firms, UILs might well be of similar, or even greater, direct importance to industry technological dynamics than is the case in the developed world. Suzigan and Albuquerque (2011), for example, argue compellingly in favour of the key role universities and PRIs have played throughout the history of some of the most successful Brazilian industries in international trade.

Nevertheless, recognizing the existence of very relevant relations between universities and firms in developing countries does not imply that this pattern of relationship is sufficient to support more ambitious endeavours. This relationship parallels other features of the development of underdevelopment. Although in both developed and developing countries universities are not the key agents in technological innovation, the full development of innovative capabilities, which should be seen as an essential task in catching up, probably requires changes in the UILs as well as improvements in university competences and in firms' capabilities. Structures and behaviours that have worked at a stage of development dominated mainly by diffusion and adaptation of foreign technology may not fit the needs of further development stages, when NSIs must be able to compete in the global arena through effective innovation.

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[8] These authors reject the distinction between innovation and diffusion, arguing that diffusion involves much more than mere adoption of technology. Besides "the acquisition of machinery and product designs, and the assimilation of related operating know how, [the] continuing process of technical change" typically involves improvement, adaptation for specific situations, and a "stream of incremental developments" (Bell and Pavitt 1993, pp. 160–161). However, they also show that, among latecomers, in just a few countries the process of technological accumulation has gone far enough to develop the capabilities required to achieve "more original innovations" (Bell and Pavitt 1993, p. 189).

   The dynamics of UILs in South Korea stand out among Asian countries and provide some important lessons about UILs (Sohn and Kenney 2007; WIPO 2007; Campos 2010). Consistent with their historical and cultural context, Korean UILs initially focused on training skilled scientists and engineers to meet increasing needs as firms conducted internal R&D (Sohn and Kenney 2007). Collaboration policy has, however, changed to include the creation of new innovation clusters and support for basic research relevant to industrial development (Campos 2010). Not only were Korean S&T policies related to UILs different from those in most developing countries, but they changed over time as the country sought new achievements throughout its catching-up period. As Kim (2002, p. 307) argues, "as industrialization progresses to the innovation stage, the role of government research institutes can become narrower in the face of rapid expansion of university research and corporate R&D activities."

6. Channels and benefits of interactions between public research organizations and industry: comparing country cases in Africa, Asia, and Latin America

Valeria Arza, Claudia De Fuentes, Gabriela Dutrénit, and Claudia Vazquez

Interactions between public research organizations (PROs) and industry have received increasing attention with the adoption of a systemic approach in the study of innovation. This perspective highlights the interactive nature of the process of knowledge generation and the central importance of intense interactions among different actors for improving the overall performance of national systems of innovation (NSIs) (Freeman 1987; Lundvall 1992; Nelson 1993). The systemic approach replaces the linear model approach and implies that PRO–industry (PRO–I) interactions are no longer viewed as mere transactions reflecting a division of labour in knowledge production – from basic to applied scientific knowledge and from there to technology development. Instead, they represent an institutionalized form of learning that contributes to the stock of economically useful knowledge in a country.

Being the product of historical development, country-specific patterns of PRO–I interactions are expected to occur. The aim of this chapter is to compare the use of different channels to transfer knowledge, and the achievement of benefits of PRO–I interactions across developing countries in Latin America, Asia, and Africa. We use a common conceptual framework and data from surveys based on similar questionnaires in four Latin American countries (Argentina, Brazil, Costa Rica, and Mexico), four Asian countries (China, Korea, India, and Malaysia), and one African country (Nigeria). The countries analysed are not developed countries yet, although they are in different stages of the catching-up process. According to the classification by the World Bank, most of them are

upper-middle-income countries, except for Korea, which is classified as high income, and India and Nigeria, which are classified as lower-middle-income countries.

Most Latin American countries were subjected to persistent instability and macroeconomic crises, which affected the long-term behaviour and performance of firms in the region (Dutrénit and Arza 2010). The literature on Latin American innovation systems has traditionally agreed that the innovative capabilities of firms are rather poor. Moreover, there has been a general perception that PRO–I relationships are weak, despite some exceptional cases (Vedovello 1997; Vessuri and Benaiges 1998; Casas et al. 2000; Cimoli 2000; Albuquerque et al. 2008; Maculan and Carvalho 2009; Dutrénit et al. 2010a). However, as a consequence of the diffusion of ideas that questioned the role of the State as the main pillar for scientific production, and pushed by funding pressures on PROs during the 1990s, a more active participation of the private sector in science and technology (S&T) upgrading has been promoted. This has encouraged firms and PROs to interact with each other for the last two decades (Dasgupta and David 1994; Slaughter and Leslie 1997; Nelson 2004; Etzkowitz et al. 2005).

In the case of Asia, a group of economies such as Japan, Korea, and Taiwan have shown rapid development of technological capabilities, moving from imitators to world-scale innovators (Hobday 1995; Kim 1997; Lee and Lim 2001). Other economies in the region (e.g., India, Thailand, Malaysia, and China), despite their rapid economic growth during the last decades and the industrialization of their economic structure, have not yet reached that level of technological sophistication (Intarakumnerd et al. 2002). As in Latin America, the governments of most of those economies also endorsed PRO–I interactions in the early 1990s, when consensus on the importance of PRO–I interaction was achieved. However, differences in the intensity of PRO–I interaction between developed and less developed countries still persist.

Africa is far behind in the indicators used to compare NSI performance. Evidence from several countries shows weak scientific and technological capabilities, and weak links between agents. Emerging PRO–I interactions have particularities; they are much more associated with human resources formation and traditional sectors.[1] What is more, differences across countries in Africa are deep (Lall and Pietrobelli 2002; Muchie, et al. 2003; Lorentzen 2009a).

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[1] This motivated a case study approach to the research in this project, which made it difficult to compare across regions (Kruss et al. 2009).

CONCEPTUAL FRAMEWORK[2]

Literature on PRO–I interactions has focused on drivers that connect – from the perspective of the firm or the researcher – and on various modes of interaction (e.g., training of human resources, open science, informal contacts, consulting relationships, joint and contract research projects, and patenting and spin-offs). These forms of interaction are classified using different criteria: the degree of formality (Eun 2009a; Perkmann and Walsh 2009; Cassiman et al. 2010; Leisyte 2011); the degree of interaction (Schartinger et al. 2002; Santoro and Saparito 2003; Perkmann and Walsh 2007; Wright et al. 2008); the direction of knowledge flows (Schartinger et al. 2002; Arza 2010); and the potential to obtain applied results (Wright et al. 2008; Perkmann and Walsh 2009).

We use the classification proposed by Arza (2010), which is based on the motivations of firms and researchers to interact. Within the literature on PRO–I links there is much research focused on the main motivations or drivers of interaction. Some examples in relation to researchers are Lopez-Martinez et al. (1994); Slaughter and Leslie (1997); Meyer-Krahmer and Schmoch (1998); Azagra-Caro et al. (2006); and Perkmann and Walsh (2008). In relation to firms, key studies are Bonaccorsi and Piccaluga (1994); Kruss (2005); Bodas Freitas and Verspagen (2009); and Brostrom et al. (2009).

Motivations for researchers working in PROs to interact with firms may be, broadly, "economic" or "intellectual." There may be institutional imperatives to diversify funding resources for infrastructure and staff support that drive interaction with industry. Researchers may also be seeking to complement their personal incomes. PRO–I interactions may also be triggered by the primary goals of the PRO to enhance the quality of research either by learning in the context of application or by learning about production technologies, which may be useful for further research. In other words, PRO–I interaction may fulfil the intellectual strategies of PROs (and researchers) by suggesting new avenues for exploration, monitoring the latest technological developments, or tackling challenging problems.

In the case of firms, the motivation to interact responds either to the need for collaboration to improve production capabilities (i.e., the role of the firm in knowledge creation is rather passive), or to the need for upgrading innovative capabilities (i.e., the role of the firm in knowledge creation is rather active). Sometimes, firms seek to interact with PROs to solve concrete and fairly simple short-term issues. Normally such firms require access to codified and ready-to-use knowledge outputs, such as

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[2] Based on Arza (2010).

testing and monitoring. On the opposite end, to cope with acceleration in technological change, firms need to gain access to the knowledge produced by PROs to "identify and exploit external and applied technological opportunities to a full extent" (Bonaccorsi and Piccaluga 1994, p. 232). Interactions through joint research and development (R&D) efforts may enable firms to gain access to scientific knowledge, which in due time will contribute to their innovative performance. Of course, this strategy demands a higher 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 motivation for PRO–I interaction as a proactive strategy.

The framework proposes that some modes of interaction better serve the actor's motivation to interact. When firms are motivated by their proactive strategies, and researchers by their intellectual efforts, they are likely to choose to cooperate by undertaking joint R&D. The combination of firm and researcher motivation illustrated in Figure 6.1 creates a taxonomy of four modes or channels of PRO–I interaction: Traditional; Bidirectional; Service; and Commercial. Following Arza and Vazquez (2010), the traditional channel includes forms of PRO–I interactions that originate in the traditional PRO functions of teaching and research (e.g., publications, training graduates for employment in industry, and

Intellectual

	(II) **Traditional** Conferences Publications Training Graduates	**(III)** **Bidirectional** Networks Joint Research
Passive: To use outputs and resources for more efficient operation		**Proactive:** To exploit knowledge resources of PROs proactively in the innovation activities of firms
	(I) **Service** Consultancy Tests Monitoring	**(IV)** **Commercial** Spin-Offs Incubators Licences

Economic

Source: Arza (2010).

Figure 6.1   *A taxonomy that groups modes of interactions into channels. Vertical line represents PRO motivation; horizontal line firm motivation*

conference participation). The commercial channel involves forms of interaction aimed at commercializing already-existing knowledge outputs (e.g., spin-off companies, patents, and incubators). The service channel attempts to solve specific production problems usually through short-term interactions (e.g., consultancy, staff training, testing, and monitoring). The bidirectional channel normally involves long-term, personal interaction with knowledge flowing in both directions (e.g., joint R&D projects and networks).

The benefits of the interaction are defined by the motivations after they become successful. Therefore, the benefits for firms would be improved production capabilities or improved innovative capabilities. Production benefits refer to short-term issues (e.g., new human resources; the use of resources available at PROs to perform tests and quality control; access to different approaches for problem solving; and contributions to the completion of existing projects). Other innovation benefits refer to long-term issues (e.g., access to highly skilled research teams from PROs; the possibility of shaping the knowledge produced within academia; the identification of new R&D projects; the selection or direction of firms' research projects; technology licences and patents; and access to university research and discoveries) (De Fuentes and Dutrénit 2012). The benefits to PROs would be intellectual or economic. Economic benefits refer to: obtaining research inputs and securing funds for laboratories; acquiring supplemental funds for the researchers' own academic research; and obtaining financial resources. Intellectual benefits refer to: knowledge exchange; ideas for new scientific and research projects; academic publications; scientific discoveries; new perspectives from which to approach industry problems; the development of human resources; and the possibility of shaping the knowledge that is being produced (De Fuentes and Dutrénit 2012).

DATA

The empirical evidence is drawn from original micro-data collected through country surveys of firms and researchers. The RoKS[3] survey of firms included questions about: innovation and R&D activities; sources of knowledge and forms of PRO–I interaction; the goals of and benefits derived from interaction; and the perception of the main role of PROs. The RoKS survey of researchers included questions about: researcher and team characteristics; forms of PRO–I interaction; and personal and institutional benefits from interaction. Table 6.1 presents basic information

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[3] The Research on Knowledge Systems (RoKS) Program of IDRC, Canada.

Table 6.1 Sample sizes and response rates for all country surveys

	Argentina	Brazil	Costa Rica	Mexico	China	India	Korea	Malaysia	Nigeria
Firms									
Sample	974	1688	566	1200	2484	nd	nd	450	nd
Response rate (%)	60	19.3	66.4	32.3	12.2	nd	nd	80.2	nd
N	592	326	376	387	302	462	600	361	139
Researchers									
Sample	2221	2151	128	3423	1238	nd	18523	nd	nd
Response rate (%)	6.1	41.4	76.5	14	16.4	nd	12.9	nd	nd
N	136	891	98	479	203	735	2395	nd	nd

Note: Some cells are incomplete (nd) because of a lack of full information in some of the country studies.

about the survey samples in Asia and Latin America. A survey of researchers was not performed in Malaysia or in Nigeria.

CHANNELS AND BENEFITS IN COUNTRY STUDIES

This section presents assessments by firms and researchers of the different channels and benefits of PRO–I interaction in each country. Because the questionnaires were assembled on the basis of a four-point Likert scale, ranging from "not important" to "very important," the assessments are presented as the percentages that assessed each mode or benefit as "moderately important" or "very important." Data are presented in horizontal bar charts. Bars represent the frequency of each option, and they are organized in decreasing order of importance. The vertical line in each chart represents the median option in terms of frequency. The comparison is subject to the availability of data in each case.[4]

Channels of Interaction: Survey of Firms

Argentinean firms (Figure 6.2) asserted that the primary mode of interaction with PROs was through informal information exchange. Two

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[4] Information on researchers is relatively poor for countries other than those in Latin America. China and India present some information, but in India no mode of interaction could be classified as commercial.
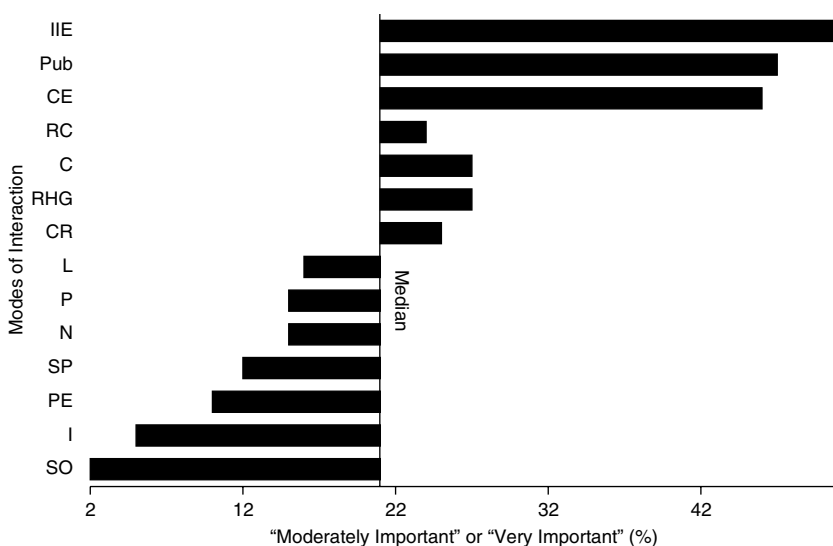
Note: C=Consultancy, CE=Conference and exhibitions, CR=Cooperative R&D, I=Incubators, IIE=Informal information exchange, L=Licensing, N=Networking, P=Patents, PE=Personnel exchange, Pub=Publications, RC=Research contract, RHG=Recently hired graduates, SO=Spin-off, SP=Scientific parks, and TS=Training staff.

Figure 6.2   Firm assessments of different modes of interaction in Argentina

traditional modes followed: publications, and conferences and exhibitions. Modes of interaction corresponding to the commercial channel (e.g., spin-off and incubators) were the least valued by Argentinean firms.

Brazilian firms indicated that publications were the main mode of interaction with PROs (Figure 6.3). Another traditional mode was among the first three (conferences and exhibitions). Cooperative R&D, a bidirectional channel, was also mentioned as an important mode of PRO–I interaction. As in the Argentinean case, spin-off and incubators were the least important modes of interaction, although the percentage of firms that judged those modes as "moderately important" or "very important" was higher than in Argentina.

Conferences and exhibitions and recently hired graduates were the most important modes of interactions for Mexican firms (Figure 6.4).[5] They

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[5] As a matter of fact, the most important mode in the Mexican case is Training staff, but as this was included only in the Mexican survey, its incidence cannot be compared with the other countries.
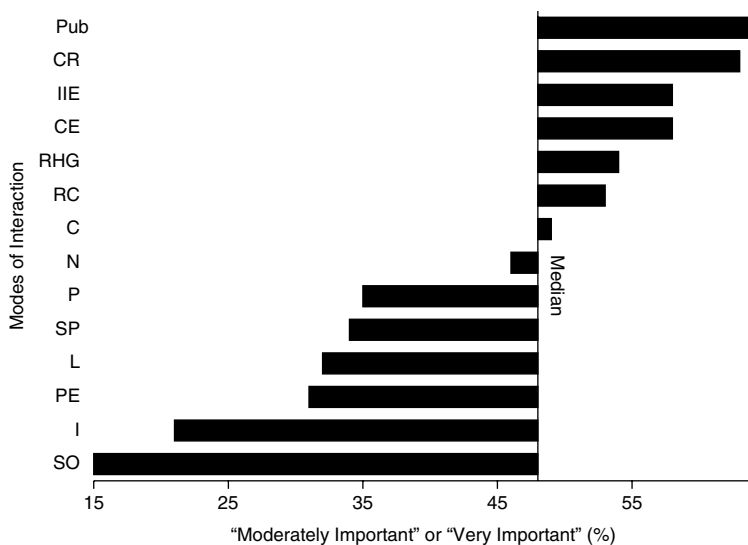
Figure 6.3   Firm assessments of different modes of interaction in Brazil
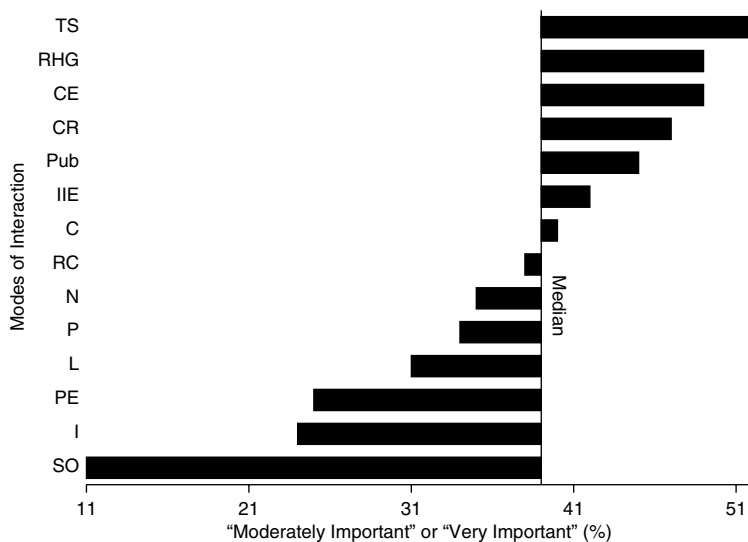
Figure 6.4   Firm assessments of different modes of interaction in Mexico
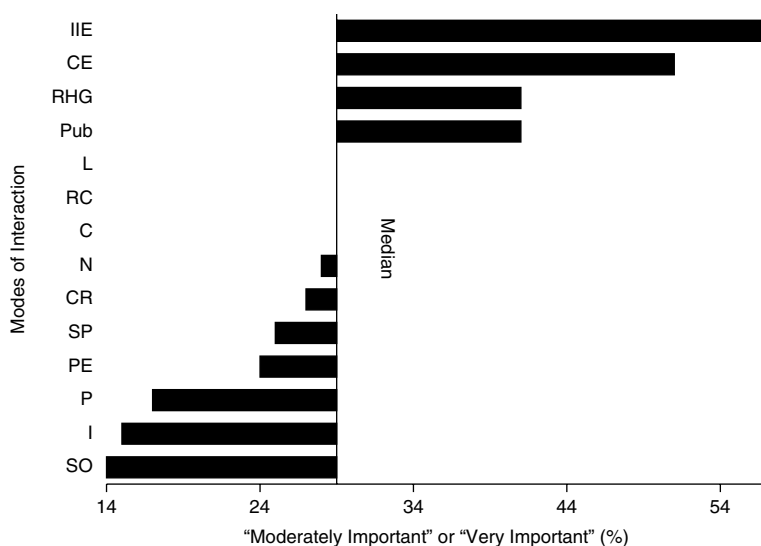
Note: See Figure 6.2 for definition of abbreviations.

Figure 6.5   Firm assessments of different modes of interaction in Costa Rica

were followed by cooperative R&D. Modes of interaction included in the commercial channel, such as spin-offs and incubators, tended to be in the last positions in the ranking.

Firms from Costa Rica first value informal information exchange with PROs (Figure 6.5). Traditional modes such as conferences and publications follow in the ranking. Bidirectional modes such as research contract, cooperative R&D, and networking were in the middle, whereas commercial modes tended to be the least valued by firms.

Chinese firms indicated cooperative R&D with PROs as the main mode of interaction (Figure 6.6). In contrast with Latin American countries, two commercial channels of interaction (patents and licensing) were the second and third most valued modes of interaction. Traditional modes of interaction (e.g., conferences or publications) were not as important in China as they were in Latin America.

Traditional modes of interactions were important for Indian firms (Figure 6.7): the most important modes of interaction were publications and conferences. Bidirectional and commercial modes were less important.

Respondents from Korea mentioned consultancy as the main mode of interaction with PROs, followed by publications and conferences
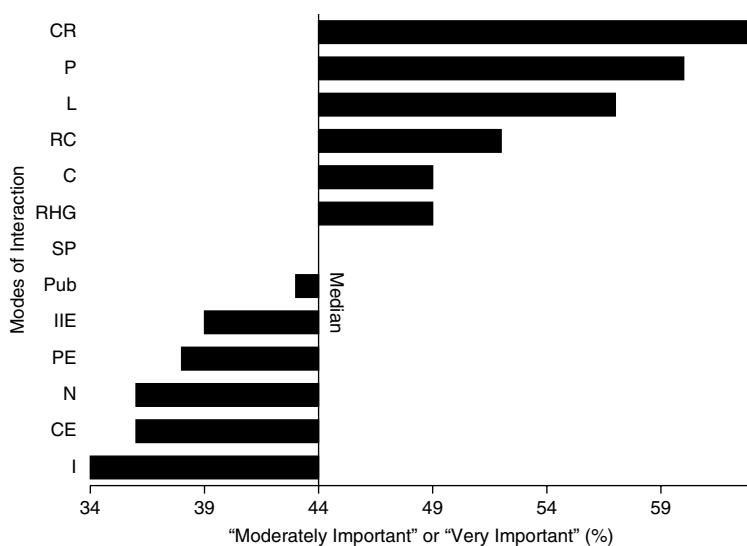
Note: See Figure 6.2 for definition of abbreviations.

Figure 6.6   Firm assessments of different modes of interaction in China
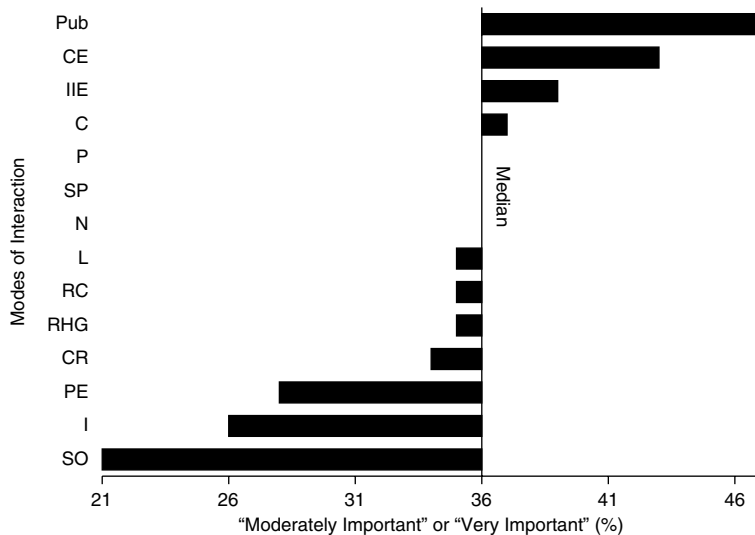
Note: See Figure 6.2 for definition of abbreviations.

Figure 6.7   Firm assessments of different modes of interaction in India
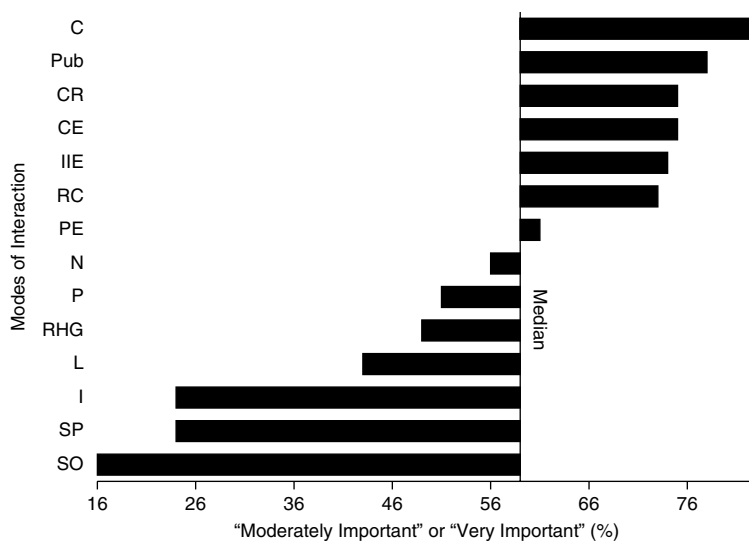
Figure 6.8   Firm assessments of different modes of interaction in Korea

(Figure 6.8). Cooperative R&D and informal information exchange were also assessed as important modes of interaction. Commercial modes were less important.

Malaysian firms were similar to those in China: patents and licensing were the main modes of interaction with PROs (Figure 6.9). Informal information exchange and conferences were next in importance.

In Nigeria, the main modes of PRO–I interaction are conferences and publications (Figure 6.10). Far less important were licensing and informal information exchanges. Bidirectional modes such as networking, research contract, and cooperative R&D are among the least valued.

In terms of modes of interaction from the perspective of firms, Latin American countries tend to favour conferences and publications and also recently hired graduates and informal information exchange. These traditional channels are better established among firms in the region. Publications and conferences are also important for Indian, Korean, and Nigerian firms. In India and Korea, consultancy, a mode from the service channel, also appears near the top of the rankings. Finally, patents and licensing were important modes of interaction for Chinese and Malaysian firms, indicating the development of a commercial channel. Interestingly, the bidirectional channel was particularly valued in China,

Note: See Figure 6.2 for definition of abbreviations.

Figure 6.9   Firm assessments of different modes of interaction in Malaysia

Note: See Figure 6.2 for definition of abbreviations.

Figure 6.10   Firm assessments of different modes of interaction in Nigeria
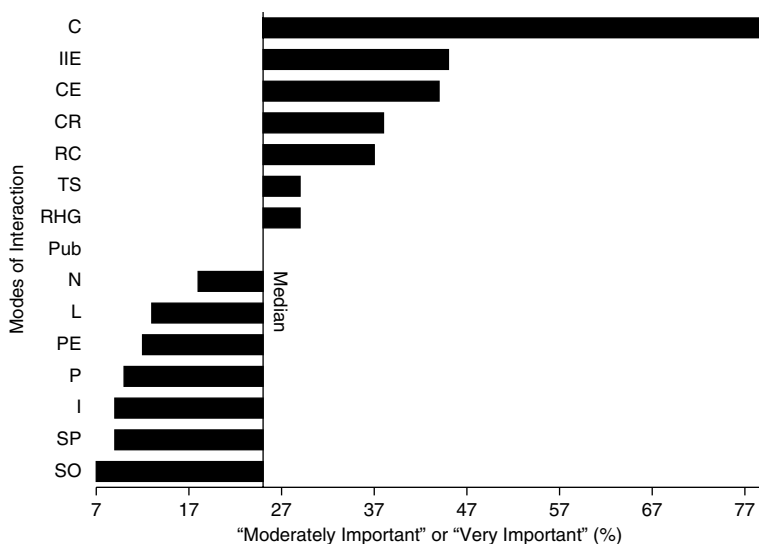
*Figure 6.11   Researcher assessments of different modes of interaction in
                Argentina*

Brazil, Mexico, and Korea, which were among the richest of the countries
analysed.

Channels of Interaction: Surveys of Researchers

Researchers in Argentina had a different opinion from firms: the most
important mode of interaction for them is not publications or conferences
but consultancy (Figure 6.11). However, other traditional modes were
next in importance (e.g., informal information exchange, and conference
and exhibitions).

   Research contracts and publications were the modes of interaction most
frequently mentioned as important by Brazilian researchers (Figure 6.12).
Conferences and cooperative R&D followed, which indicated the prevalence
of traditional and bidirectional channels. Modes of interaction included in
the commercial channel were in the lowest positions of the ranking.

Figure 6.12 *Researcher assessments of different modes of interaction in Brazil*

Results from the survey of researchers in Costa Rica were highly compatible with the results from firms (Figure 6.13). Informal information exchange, publications, and conferences were the main modes of PRO–I interaction.

Mexican researchers pointed to cooperative R&D as the main mode of interaction with industry, followed by informal information exchange (Figure 6.14). Research contracts were next in importance, which shows the importance researchers allocate to bidirectional channels. Publications and recently hired graduates were not as important to researchers as they were to firms in Mexico.

Chinese researchers assessed research contracts as the primary mode of interaction with industry (Figure 6.15). This was followed by informal information exchange and conferences. Unlike Chinese firms, cooperative R&D was not among the preferred modes of interaction for researchers.

Finally, researchers in India allocated highest importance to conferences and exhibitions and consultancy (Figure 6.16).

The modes of interaction favoured by researchers differed from those favoured by firms. In general, the service channel tended to be more valued by researchers than by firms. That was the case in Argentina,
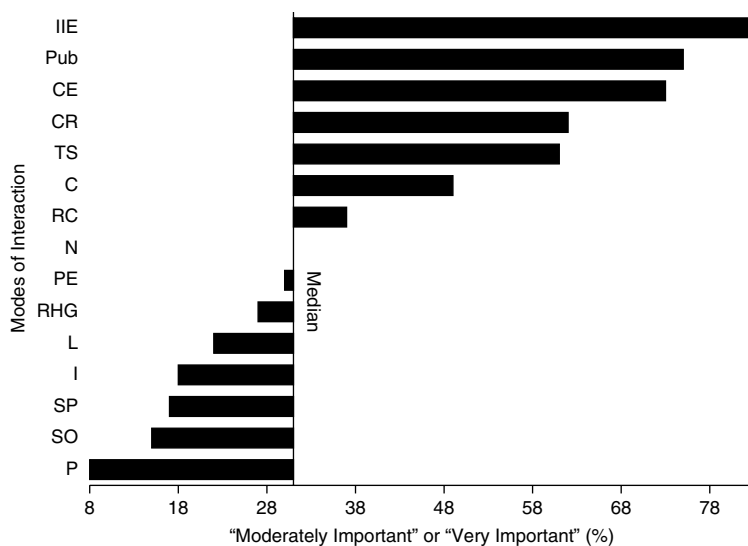
Note: See Figure 6.11 for definition of abbreviations.

Figure 6.13   Researcher assessments of different modes of interaction in Costa Rica

Mexico, Costa Rica, and China. Indian researchers also valued the service channel, but in this case, firms also preferred that channel. Another interesting observation is the relatively high importance researchers placed in the traditional channel: in most countries many of the traditional modes were above the mean. Finally, the data suggested that researchers in Brazil, Mexico, and China were interested in interacting with the industry to perform research activities.

Benefits of Interaction: Surveys of Firms

In terms of benefits from the interaction, Argentinean firms highlighted benefits related to short-term production activities: they stated that the main benefits they received from interacting with PROs were related to the possibility of performing tests and receiving help with quality control. In contrast, firms did not usually perceive that their interactions with PROs improved their long-term innovative performance (Figure 6.17).

Brazilian firms considered that their main rewards from interacting with PROs were related to opening up options to solve short-term production problems rather than improving their long-term innovative performance

Figure 6.14 *Researcher assessments of different modes of interaction in Mexico*

Figure 6.15 *Researcher assessments of different modes of interaction in China*

*Figure 6.16   Researcher assessments of different modes of interaction in
          India*

(Figure 6.18). In this case, the possibility of performing tests and using
PRO resources were among the most important rewards.

The case of Costa Rica was less clear cut (Figure 6.19). Firms appeared
to benefit from interacting with PROs in the form of technological advice
and information about R&D trends, which means that firms perceived
that interactions improved long-term innovative performance. However,
these rewards were fairly abstract (in contrast to research contracts), and
were likely to be the result of informal conversation rather than being the
output of systematic efforts to exchange technological information (infor-
mal information exchange was the highest valued mode of interaction by
Costa Rican firms).

The case of Mexico was similar to the cases of Argentina and Brazil:
rewards were related to short-term production benefits, although in
this case they were mainly focused on the provision of trained human
resources (Figure 6.20). Performing tests was another important reward of
PRO–I interactions for Mexican firms.

Chinese firms tended to get long-term benefits related to innovation
strategies from their interactions with PROs (Figure 6.21). Mainly,
they mentioned that PRO–I interactions had augmented their ability to
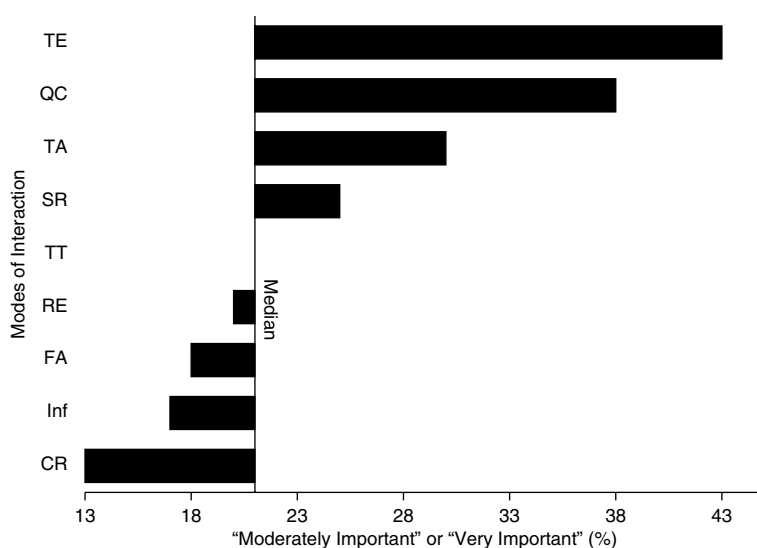
Note: CR =Contract research the firm does not perform, CRInn=Contract research to contribute to the firm's innovative activities, FA=Augment firm's ability to find and absorb technological information, Inf=Get information about trends in R&D in the field, QC=Help in quality control, RE=Use resources available at PRO, SR=Make earlier contact with university students for future recruiting, TA=Get technological and consulting advice to solve production problems, TE=Perform test for products and processes, and TT=Technology transfer from the university.

Figure 6.17   Firm assessments of benefits of interaction in Argentina

absorb technological information and contributed to the firms' innovative activities. Chinese firms did not seem to gain much reward from human resources trained by PROs.

Malaysian firms highlighted benefits related to short-term production activities (Figure 6.22). Among the most frequently mentioned as important were: the possibility of making early contact with university students; receiving help in quality control; and performing tests for products or processes. Information about trends in R&D and contract research, whether to complement or supplant the firm's innovative activities, were less frequently mentioned as important by Malaysian firms.

In India, firms perceived that the most important benefits were related to improving their short-term production capacity in the form of quality control, tests, and the use of resources available in PROs (Figure 6.23).

Korea was rather similar to China (Figure 6.24). Firms perceived they benefited from PRO interactions by improving their innovative capacity. The most valued benefits of PRO interactions were: receiving technological
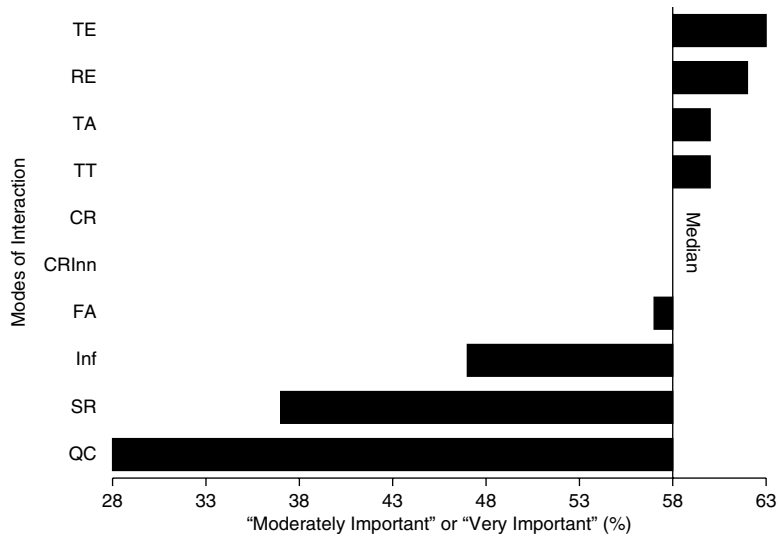
Note: See Figure 6.17 for definition of abbreviations.

Figure 6.18   Firm assessments of benefits of interaction in Brazil
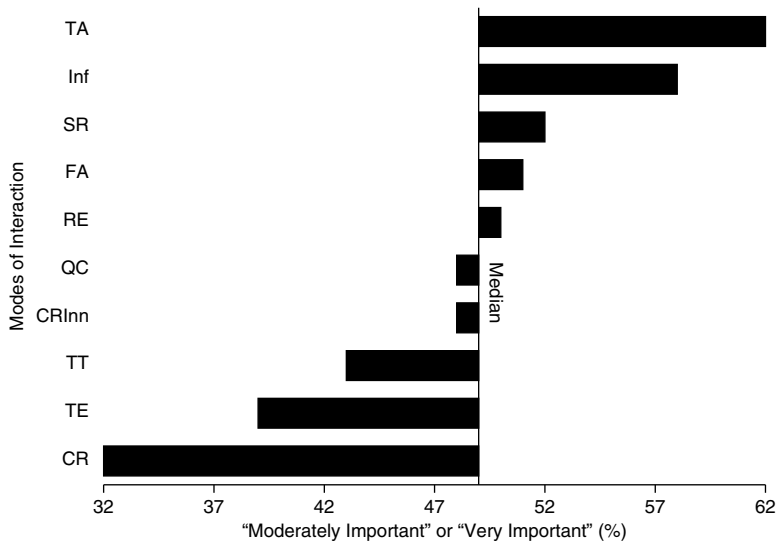
Note: See Figure 6.17 for definition of abbreviations.

Figure 6.19   Firm assessments of benefits of interaction in Costa Rica
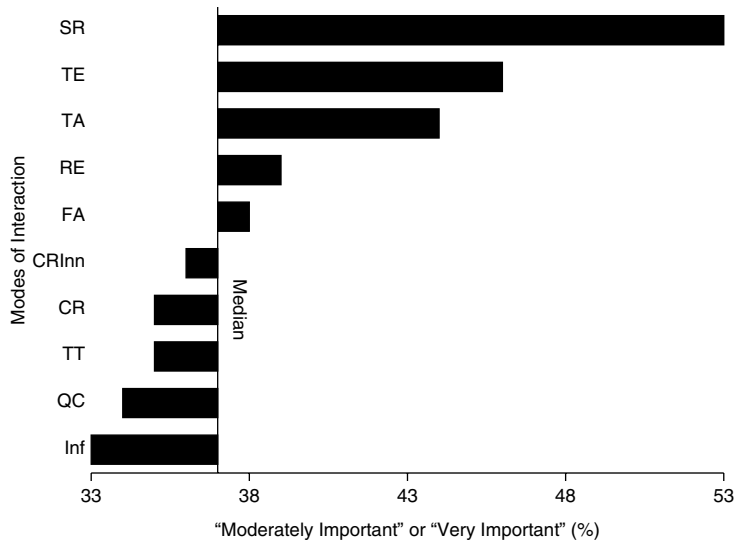
Figure 6.20   Firm assessments of benefits of interaction in Mexico
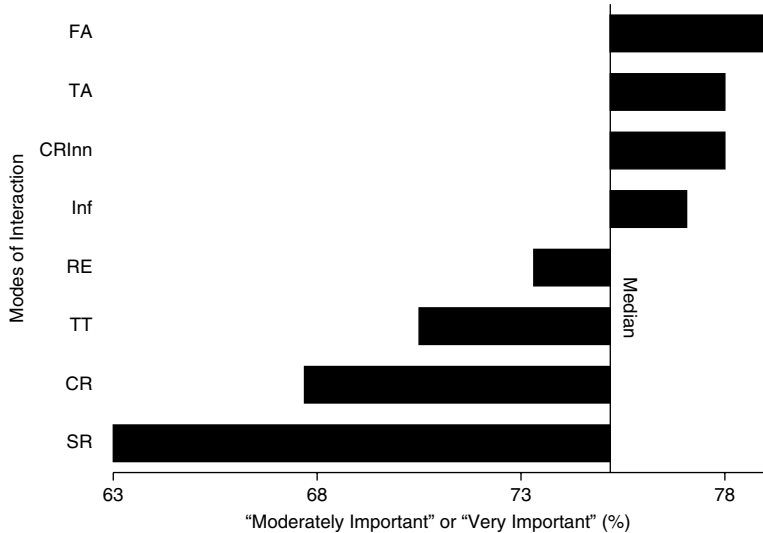
Figure 6.21   Firm assessments of benefits of interaction in China
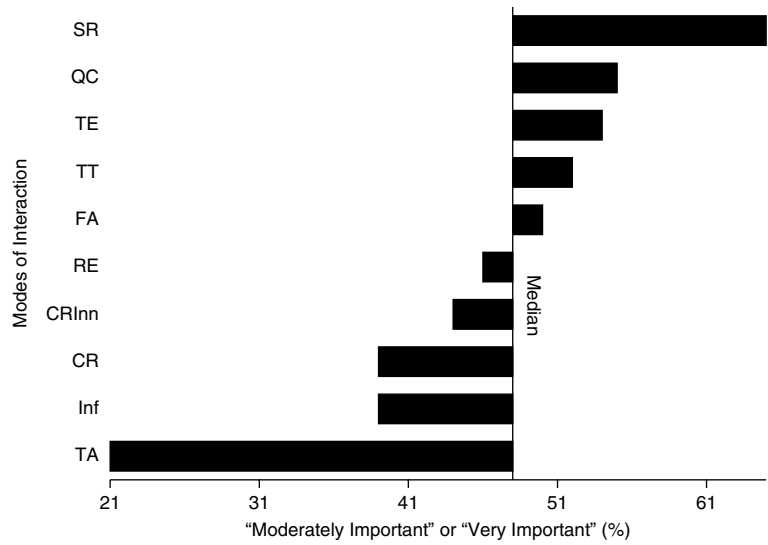
Figure 6.22   Firm assessments of benefits of interaction in Malaysia
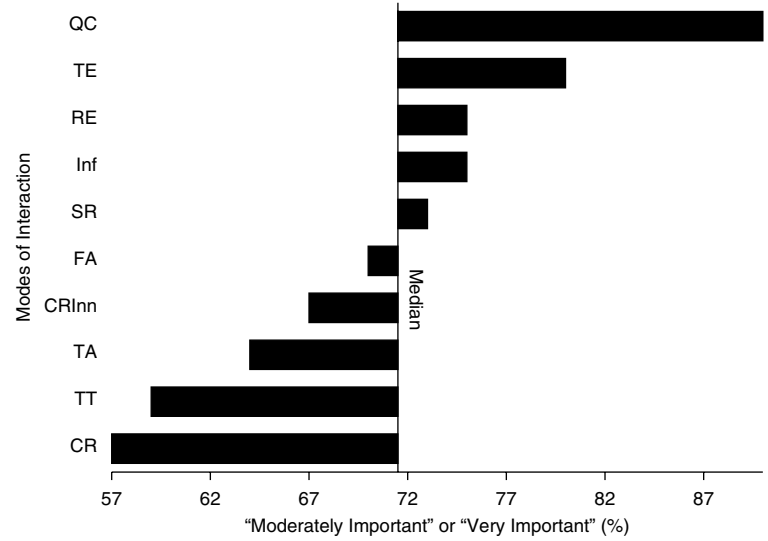
Figure 6.23   Firm assessments of benefits of interaction in India
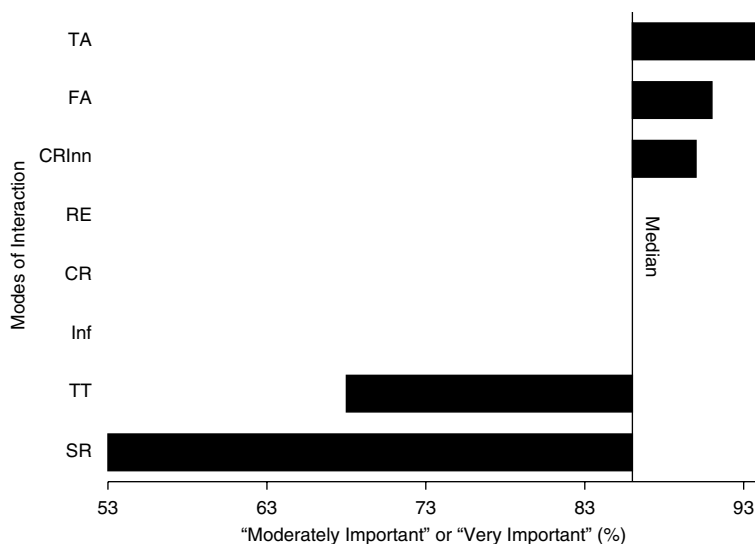
Note: See Figure 6.17 for definition of abbreviations.

Figure 6.24   Firm assessments of benefits of interaction in Korea

advice; augmenting the firm's ability to absorb technological information; and contract research to contribute to the firms' innovative activities.

Finally, Nigerian firms, just like those in Brazil, Argentina, Mexico, India, and Malaysia, perceived that the most important benefits were related to helping in short-term production capacity (e.g., quality control and tests). Some long-term benefits were also identified as important: contributing to the firm's innovative activities, and augmenting the firms' ability to absorb technological information (Figure 6.25).

Interestingly, most firms across the different countries (Argentina, Brazil, Mexico, India, Malaysia, and Nigeria) perceived that their benefits from PRO–I interactions were related to the possibilities of improving their (short-term) productive performance. Only in China and Korea did firms perceive that the most important rewards from interactions were those that improved their (long-term) innovative capabilities. The case of Costa Rica was more difficult to assess because it seemed that firms benefited by obtaining technological information, although this exchange seemed to be fairly informal.
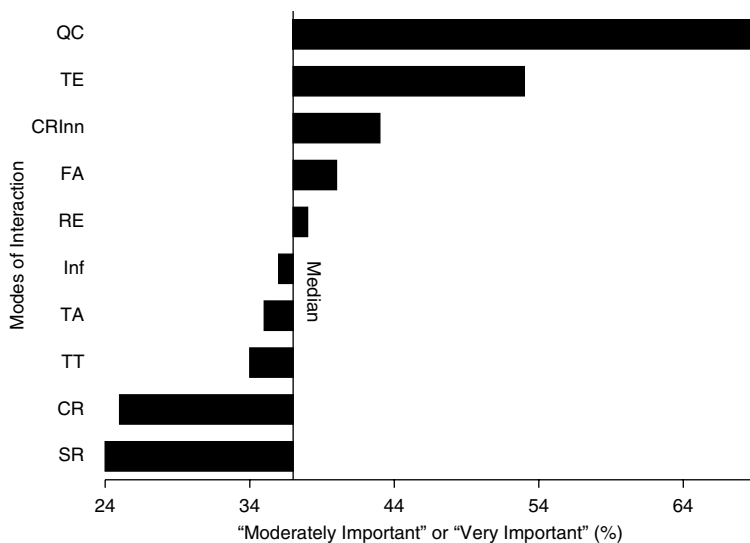
Figure 6.25   Firm assessments of benefits of interaction in Nigeria

Benefits of Interaction: Surveys of Researchers

Researchers in Argentina frequently mentioned the importance of sharing knowledge and information and of inspiration for further scientific research (Figure 6.26). Economic benefits, such as financial resources, provision of research inputs, and sharing of equipment were less frequently mentioned.

Researchers from Brazil assessed the main benefits of interaction as the sharing of knowledge and information and getting ideas for collaborative projects. Economic benefits were less valued (Figure 6.27).

Results from Costa Rica indicated that researchers felt they improved their reputations when they interacted with industry (Figure 6.28). Sharing of knowledge and getting ideas for additional collaborative projects were also seen as important benefits.

Mexican researchers tended to prioritize intellectual benefits (Figure 6.29). Ideas for additional collaborative projects, inspiration for scientific research, and sharing of knowledge and reputation were the most valued benefits of PRO–I interactions. Financial resources, provision of research inputs, and sharing of equipment were at the bottom of the rankings.

Chinese researchers assessed provision of research inputs as the main
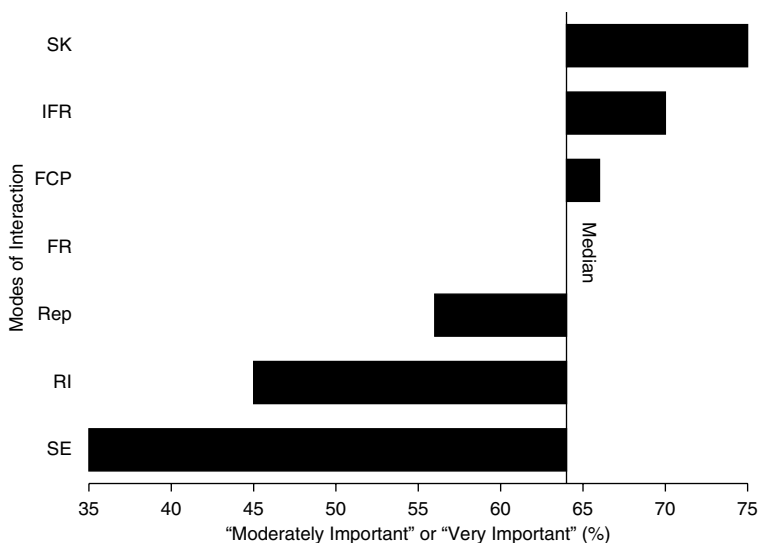
Note: Dem=Demanded by the school or department, Edu=Help with student education and support, FCo=Considering funding a company, FCP=Ideas for further collaborative projects, FR=Financial resources, IFR=Inspiration for further scientific research, Rep=Reputation, RG=Necessary to get research grants, RI=Provision of research inputs, SE =Share equipment and instruments, and SK=Share of knowledge and information.

Figure 6.26   Researcher assessments of benefits of interaction in Argentina

benefit from interacting with firms, but they also valued intellectual benefits such as sharing knowledge and ideas for future research (Figure 6.30).

In India, researchers perceived that intellectual benefits were the most frequent rewards of PRO–I interactions, particularly in the form of helping with student education and support, and sharing knowledge (Figure 6.31). In addition, the provision of research inputs was highly valued.

Finally, similarly to the other Asian cases, Korean firms perceived that intellectual benefits were the most important – particularly in the form of new ideas for collaborative projects and student education and support (Figure 6.32). As in India and China, research inputs were also highly valued.

Interestingly, researchers in all countries included in this study perceived that long-term intellectual benefits were the main rewards from PRO–I interactions. However, although in Latin America short-term economic benefits were the least valued among the potential rewards, all Asian countries highly valued the provision of inputs for additional research. In Asia,
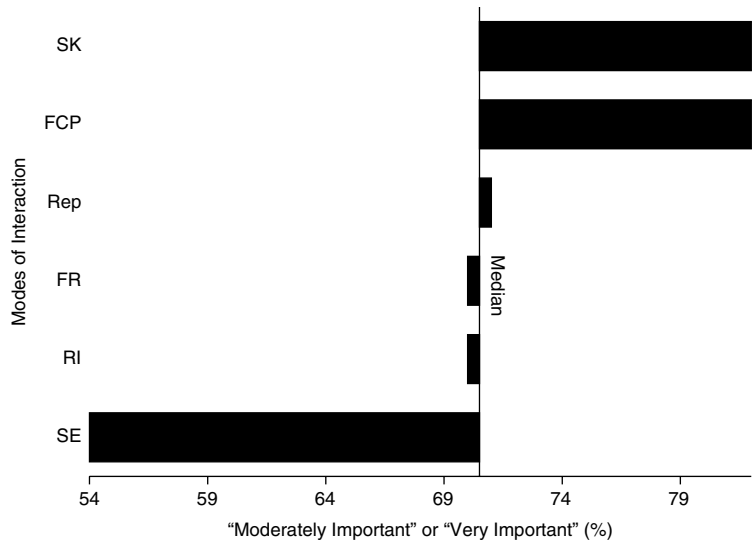
Note: See Figure 6.26 for definition of abbreviations.

Figure 6.27   Researcher assessments of benefits of interaction in Brazil
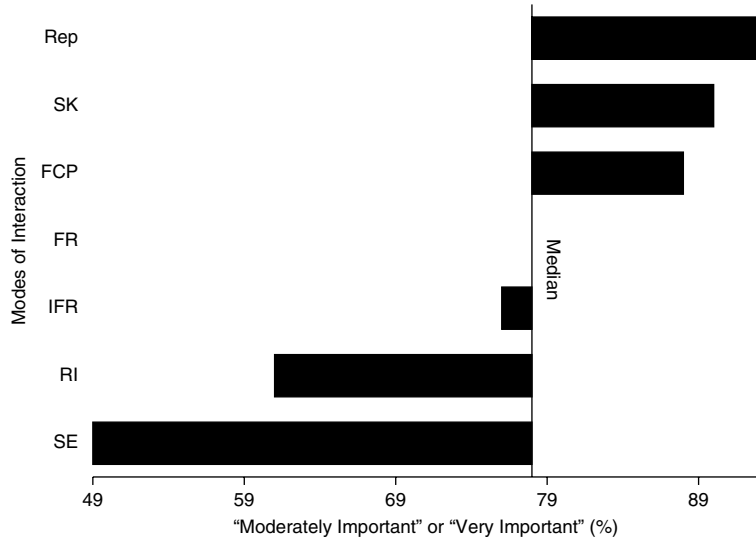
Note: See Figure 6.26 for definition of abbreviations.

Figure 6.28   Researcher assessments of benefits of interaction in Costa Rica
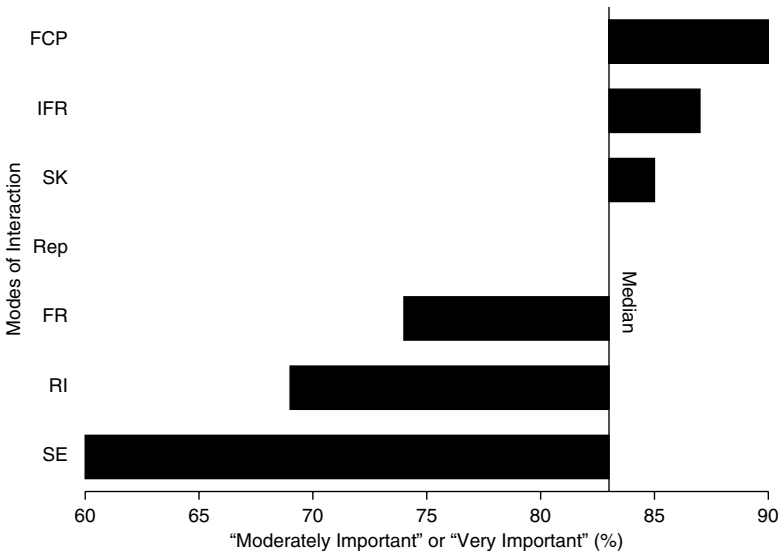
Note: See Figure 6.26 for definition of abbreviations.

Figure 6.29 Researcher assessments of benefits of interaction in Mexico
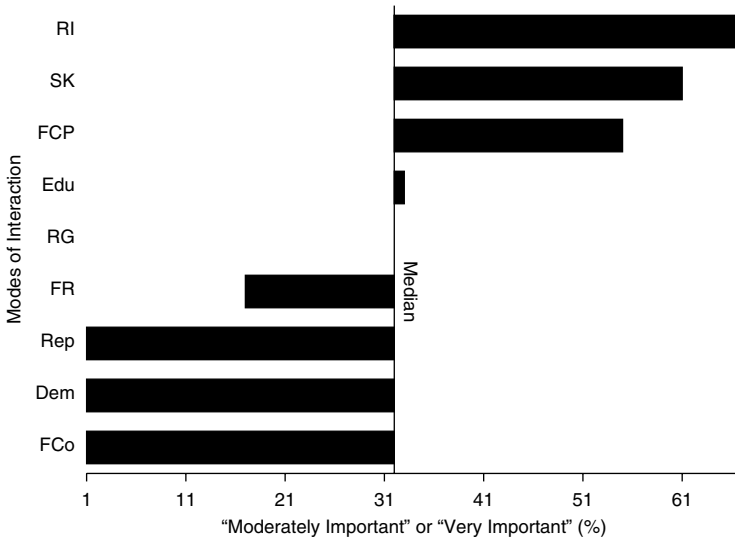
Note: See Figure 6.26 for definition of abbreviations.

Figure 6.30 Researcher assessments of benefits of interaction in China
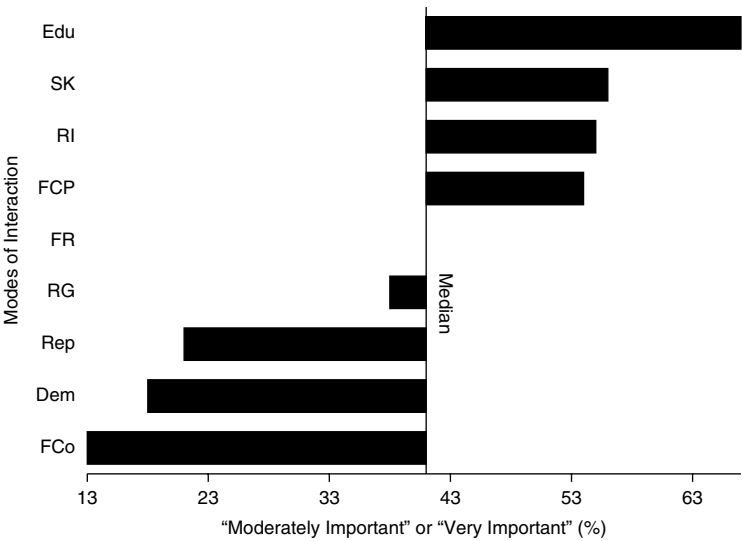
Note: See Figure 6.26 for definition of abbreviations.

Figure 6.31   Researcher assessments of benefits of interaction in India
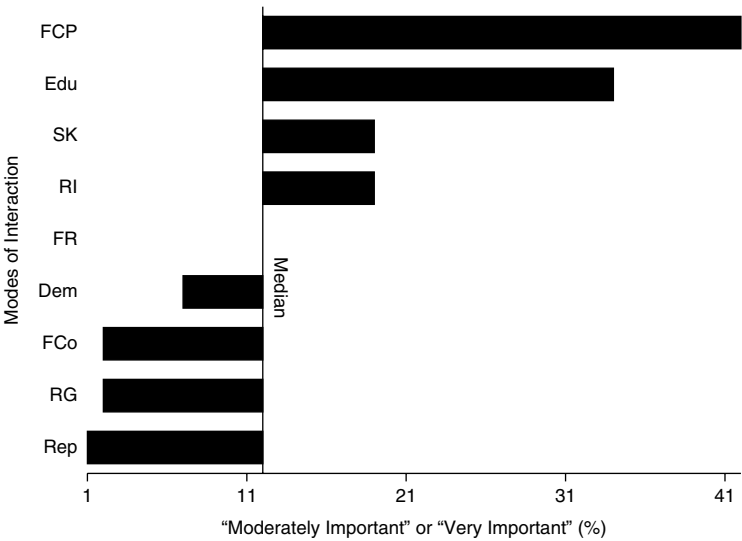
Note: See Figure 6.26 for definition of abbreviations.

Figure 6.32   Researcher assessments of benefits of interaction in Korea

economic and intellectual benefits were more balanced, whereas in Latin America, intellectual benefits were clearly seen as more important.

CONCLUSION

This chapter compared the use of channels, and the achievement of benefits of PRO–I interactions, across developing countries in Latin America, Asia, and Africa. The results suggested that firms and researchers were positive in relation to PRO–I interactions; in fact, researchers were on average more positive about PRO–I interaction than firms. This is in line with findings by Bekkers and Bodas Freitas (2008). The data showed different patterns in the use of channels of interaction by country, but the perception of benefits from interaction was more homogeneous across countries. That is, most researchers gave more importance to intellectual over economic benefits, whereas most firms preferred short-term benefits.

In terms of channels of interaction for firms and researchers, Latin American countries showed more similar patterns within the region than Asian countries. Researchers in Latin America would be located in the first, second, and third quadrants of the taxonomy of channels (Figure 6.1). The most important channels of interaction for researchers in Latin America were the traditional and services channels. In addition, in Brazil and Mexico, researchers recognized the bidirectional channel as one of the most important during PRO–I interactions. Research contracts and cooperative R&D were among the most important modes within the bidirectional channel for Brazil and Mexico.[6] In contrast, we did not observe a regional pattern for researchers in the two Asian countries (China and India). Researchers in China would be identified in the third quadrant, with the bidirectional channel as the most important, whereas researchers in India would be identified in the second quadrant, as traditional channels are among the most relevant.[7]

Data show that firms and researchers across the different countries perceived the commercial channel to be the least important during PRO–I interactions; other findings from developed countries revealed the same result (Cohen et al. 2002; D'Este and Patel 2007). Although the commercial channel tended to be last in importance for firms as well, we found that firms assigned a higher value to the commercial channel than researchers – mostly patents and licensing, not setting up new businesses.

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[6] For a more detailed discussion of the Latin American countries, see Chapter 3, this book.
[7] For a more detailed discussion of the Asian countries, see Chapter 2, this book.

In particular, firms in China identified patents and licensing as the second and third most important modes of interaction.

The most entrepreneurial modes within the commercial channel (e.g., incubators and spin-offs) were infrequent choices for both researchers and firms. This might have been due to the fundamental distinctive features of incubators and spin-offs. Unlike other more frequently used channels (e.g., cooperative R&D, patents, consultancy, and informal information exchange), incubators and spin-offs can only be used after researchers have gained a certain level of confidence in launching a new business enterprise with their own creative ideas. The knowledge that researchers in PROs transfer to industrial firms (e.g., through cooperative R&D, technical consultancy, and informal information exchange) is not necessarily new or likely to provide powerful ideas upon which one could launch a new business enterprise.

In terms of channels of interaction from the firms' perspective, data show that firms would be located in the first, second, or fourth quadrants of the taxonomy (Figure 6.1). Most of the firms valued the traditional or services channels as the most important for interaction. The exceptions were China and Malaysia, which assigned more value to proactive forms of interaction, such as the bidirectional (research contracts and cooperative R&D) and commercial channels, although they chose the least proactive interaction modes (licensing and patents rather than spin-off companies).

Our studies of the channels of interaction highlight two issues. First, firms and researchers in Latin America show more similar patterns of PRO–I interactions within the region than Asian countries. Second, within countries, firms and researchers tend to agree on the extent to which they use different channels of interaction, which supports the validity of our taxonomy. However, in Latin America, researchers are relatively keener on using the bidirectional channel than firms, which suggests that they expect interactions to be intellectually rewarding.

In terms of the benefits from interaction, firms in Argentina, Mexico, India, and Nigeria consider that PRO–I interactions bring benefits related to short-term production activities, rather than benefits related to long-term innovation strategies. Firms in these countries tend to use the traditional channel (i.e., graduates, publications, and conferences) more often than any other channel. Firms in Brazil, Costa Rica, China, Korea, and Malaysia claim to have received as many long-term benefits as short-term benefits from their interactions. These results suggest that in some emerging economies there is still an urge to develop policies that foster the use of more proactive channels, such as the bidirectional channel, that leads to more long-term innovation benefits for firms, and is associated with improved innovation capabilities.

Interestingly, from the viewpoint of the researchers, the results were similar for most of the countries. Researchers claimed to receive more intellectual benefits than economic benefits. These results suggest that firms received shorter-term benefits from PRO–I interactions than did researchers. This suggests that the nature of the knowledge appropriated differed for the two types of agents. Several factors may explain this difference in behaviour.

To conclude we would like to sketch some policy implications that can be derived from our comparisons across countries. However, we must first highlight that country specifics prevailed. Rather than designing uniform policy prescriptions to foster PRO–I interactions, policymakers must look at their own specifics to design the correct policies to change or reinforce the behaviour of various agents. Still, some common policy recommendations can be suggested:

1. The evidence suggests that firms and researchers assign more importance to channels of interaction located in the first and second quadrants of Figure 6.1, which are associated with more passive forms of interaction. Thus, policies should be designed to promote interactions that aim to create more proactive use of knowledge and promote more long-term innovation benefits for firms.
2. Researchers place more value on intellectual benefits than on economic benefits; therefore, policies should be designed to foster modes of interaction that can be rewarding both intellectually and in terms of long-term profit making for firms.
3. One challenge for PRO–I interactions is to be able to move forward from more passive forms of interaction to more proactive modes of interaction. In the search for intellectual benefits, the challenge will be to keep using the traditional channel, while moving forward to better exploit the bidirectional channel.

7. Matrices of university–firm interactions in Latin America

**Eduardo Albuquerque, Wilson Suzigan,
Valeria Arza, and Gabriela Dutrénit**

Investigations of interactions between firms and universities have a long tradition in the evolutionary economics literature. The subject of this chapter – matrices that relate economic sectors to science and engineering (S&E) fields – builds on this tradition. We refer to the contributions by Rosenberg (1972, 1982) on lessons from history; Freeman and Soete (1997) and Colyvas et al. (2002) on case studies of technologies, inventions, and technology transfer from universities and research institutes to firms; Schmoch (1997) on patents from research institutes and papers from firms; Narin and Noma (1985), Narin et al. (1997), NSB (2002, 2004, 2006), Verbeek et al. (2002), Callaert et al. (2006) and Ribeiro et al. (2010) on non-patent references in patents; Zitt et al. (2003) on geographical co-localization of patents and papers; and finally Klevorick et al. (1995) and Cohen et al. (2002) on sources of technological opportunities and how US manufacturing firms use and value knowledge flows from universities and research institutes.

The last two contributions, the Yale survey on industrial research and development (Yale survey) and the Carnegie Mellon survey on industrial research and development (R&D) (CM survey), are particularly relevant to the purposes of this chapter because they both use survey data. Cohen et al. (2002) prepared the first matrix of interaction between industrial sectors and S&E fields for the US. This matrix (Cohen et al. 2002, Table 3, p.11) was a pioneering academic product that showed how specific S&E fields contributed to specific industrial sectors as sources of knowledge for their innovation. The information provided by this table is a valuable research tool for assessing university–industry links (UILs) and for making international comparisons.

The starting point for Cohen et al. (2002) was the previous work by Klevorick et al. (1995), which evaluated the "advance of scientific understanding" as an important source of technological opportunity and a key determinant of technological progress. The authors used the Yale survey

to ask firms about the relevance of science to industrial technology. The answers provided information to explore "interindustry differences in the strength of science" (Klevorick et al. 1995, p. 193). The investigation involved 650 R&D managers in 130 lines of business.

The findings presented by Klevorick et al. (1995, pp. 194–195) shed new light on understanding interactions between science and technology (S&T). They confirmed empirically what educated guesses might suppose. In their words, "the lists of particular sciences that the various industries identified as important for their technological progress contain few surprises; neither do the lists of industries in which each science is most relevant." They show that S&E fields such as "medical science and biology are rated as important by the industries that one intuitively believes are closely connected with them, drugs and medical/surgical instruments for medical science; drugs, pesticides, animal feeds for biology." They also showed that "industries related to agriculture almost always rate agricultural science as important, and they also often give high marks to biology and chemistry." Klevorick et al. (1995) explain that "industries that are generally deemed to employ chemical-based technologies (drugs, organic chemicals, plastics, petroleum refining, pulp and paper) all judged chemistry to be important." And, finally, they indicate that "materials science, computer science, and sometimes physics were rated as important by industries like semiconductors, computers, and communications equipment."

What was important was the empirical confirmation that these industries relied on S&E to access the new knowledge they needed to innovate, and that this knowledge was produced by universities and research institutes. Klevorick and his colleagues evaluated those findings as not surprising. Certainly, for researchers studying the sources of information for innovation, the findings were a confirmation. But for policymakers, the results provided important information to avoid the downsizing of high-education and research institutions. For researchers at the periphery of capitalism, a question was immediately raised: could this pattern of interaction be replicated in developing countries?

The analysis by Cohen et al. (2002) was a step forward in the investigation of the relevance of science to industrial innovation. Their paper focused on "the influence of public research on industrial R&D." They investigated 1252 firms from 34 different sectors, and asked firms "to evaluate, by field, the importance to their R&D (on a four-point Likert scale) of the contribution of public research conducted over the prior ten years for each of ten fields: biology, chemistry, physics, computer science, medical and health science, chemical engineering, electrical engineering, mechanical engineering, and mathematics." The responses were organized in a matrix that indicated, for each industry, the percentage of firms

that reported an S&E field as at least moderately important (score 3) for their R&D (see Cohen et al. 2002, Table 3, p. 11). This matrix provides a benchmark for this chapter. It is a useful research tool and also a useful reference for policymaking.

Three observations by Cohen et al. (2002) suggest how one may read their matrix. First, as previously described by Klevorick et al. (1995), they stress that "[a]s may be expected, more respondents consider research in the engineering fields to contribute importantly to their R&D than research in the basic sciences, except for chemistry." The relationship between S&E fields and manufacturing sectors is once more confirmed: "the impact of public research in chemical engineering is most apparent in the petroleum and selected chemical industries"; "the impact of public research in mechanical engineering is most evident in general purpose machinery, glass and somewhat in the transportation-related group of industries"; and "electrical engineering is considered to be particularly important across the range of industries concerned with electronics, including computers, semiconductors, communications equipment, and instruments, as well as auto parts and glass" (Cohen et al. 2002, p. 10).

Second, Cohen et al. (2002, pp. 10, 12) look at the role of applied sciences, and differentiate between them with regard to the pervasiveness of their impact: "the impact of public research in the applied sciences suggests that the influence of medical and health science is strong in the drug and medical equipment industries." As well, "the impact of the other two applied sciences considered, namely materials and computer science, is much more pervasive – indeed more pervasive than any basic science or engineering field." Therefore, this matrix is also suitable for evaluating the pervasiveness of S&E fields. According to Cohen et al. (2002, p. 12), "the field with the most pervasive direct impact on industrial R&D is materials science. Half or more of industry respondents scored materials science as at least 'moderately important' to their R&D activities in 15 of our 33 manufacturing industries, spanning the chemicals, metals, electronics, machinery, and transportation equipment industries. If any discipline can be awarded the title of a 'general purpose' research field for the manufacturing sector, it is materials science."

Third, Cohen et al. (2002, p. 12) help to evaluate the overall impact of the scientific infrastructure on industrial innovation. They describe how the impact of public research is pervasive: "In 26 of the 34 industries, half or more of the respondents reported at least one public research field to be at least moderately important, and half or more of the respondents in 14 of the industries reported public research from at least two fields to be at least moderately important."

This brief summary of Klevorick et al. (1995) and Cohen et al. (2002)

suggests that matrices that relate S&E fields and economic sectors are powerful research tools. They may help to evaluate the scientific infrastructure and guide the design of public policies in developing countries.

The preparation of matrices like these for developing countries became an important research goal. A number of research questions can be raised: What shape might those matrices have in developing countries? How populated would the matrices be in these countries? Would there be differences in the importance of specific S&E fields to different industrial and economic sectors? Which would be the most pervasive S&E fields? Questions like these organized the research effort for this chapter.

It is important to emphasize that in their analyses Cohen et al. (2002) looked mainly at matrix cells in which "half or more of the respondents" reported that a specific S&E field was at least moderately important to a specific industry. In this chapter, a matrix cell with this feature will be analysed as a "point of interaction." This concept organizes the discussion and country comparisons in the chapter. The research questions may be rephrased to identify points of interaction between S&E fields and economic sectors in matrices from developing countries and understand their position – which pairs (S&E fields and economic sectors) are important, what logic is behind them, and how spread out are they in the matrices. The argument of the chapter is that there is history behind each point of interaction – a long-standing co-evolutionary process of construction of relationships between research institutions and firms. The identification of points of interaction may help in understanding the specificities of interactions between S&T in developing countries.

METHODOLOGY

The matrices of interaction of economic and industrial sectors with S&E fields for Argentina, Mexico, and Brazil were based on data collected by surveys of firms conducted within the RoKS project (see Introduction, this book). The results were then compared with the pioneering matrix prepared by Cohen et al. (2002, p. 11).

Matrices were prepared for Argentina (355 firms), Mexico (387 firms), and Brazil (325 firms). The specificities of the three sets of firms are relevant. The most important difference was the interactive nature of the firms that answered the questionnaires. The Argentine and Brazilian samples included only firms that interacted with public research organizations (PROs), whereas the Mexican sample included both linked and non-linked firms. These differences are relevant for comparisons between the three Latin American matrices. In the same way, although the Yale and the CM

surveys interviewed R&D-performing firms that did not necessarily have interactions with universities, the Latin American surveys interviewed interactive firms that did not necessarily perform in-house R&D. This is another difference that must be kept in mind when comparing the results from the three Latin American countries with those from the US.

The Argentine survey was organized as part of the larger National Innovation Survey, carried out in December 2007 and managed by the National Institute of Statistics and Censuses (INDEC 2008). A special section was included in the National Innovation Survey and sent to 590 industrial firms that had reported interactions with PROs in the innovation survey the previous year. They represented 35% of the total number of firms included in the National Innovation Survey. The response rate to this section was 60% (355 firms), and the data refer to 2005.

The definition of interactions was very broad: it ranged from joint R&D projects to informal information exchange. Organizations included as PROs were: universities, public research institutes (for industry and agriculture), and other government organizations for S&T.

In Mexico, the firms were selected from lists of firms that had participated in different projects or programmes managed by federal and regional government agencies related to science, technology, and innovation (e.g., fiscal incentives for R&D, and sectoral funds to finance problem-oriented research). A total of 1200 firms were included and 70% of them had benefited from public funds to foster R&D and innovation activities. The response rate was 32.3%. The sample included 387 innovative firms from all sectors; non-innovative firms were excluded. Of these firms, 67% performed R&D; 42% received fiscal incentives for R&D; and 75% had links with PROs (67% with universities and 47% with public research centres). The composition between linked and non-linked firms differed between sectors. The characteristics of this sample did not differ from the major National Innovation Survey of 2006, where half of the innovators performed R&D activities, and 65% used PROs as information sources.

The survey was voluntary; therefore, there is probably a bias toward PRO–industry interaction. Researchers and firms that actually interact were keener to answer the questionnaire. In addition, the survey included a large proportion of firms with access to public funds to foster R&D, thus they may perform R&D activities. The definition of PROs included universities, other higher education institutions, and public research centres.

The database for the Brazilian matrix was constructed from information available in the Censo do Diretório dos Grupos de Pesquisa (DGP), organized by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq). The information collected was from the 2004 census, published in 2006.

The DGP lists research groups from universities, higher education institutions, and public research institutes. In the 2004 census, 2151 research groups reported that they interacted with 3875 production units – firms and other types of organization. To construct the database, organizations such as state agencies, municipalities, ministries, secretariats, non-government organizations, and associations of all sorts were excluded. This procedure left us with 1688 firms. From April to November 2009, a questionnaire was sent to the individuals in charge of interactions with researchers from universities and public research institutes; 326 firms answered the questionnaire[1] (a 19.3% return rate).

THE THREE LATIN AMERICAN MATRICES OF INTERACTION

The matrices of interaction between economic sectors and S&E fields were created for Argentina, Mexico, and Brazil. The S&E fields most demanded by firms, and the economic sectors that have the most links to S&E fields in each country, are discussed. The discussion is based on the concept of points of interaction – a matrix cell in which 50% or more of the firms in a given sector indicate a specific S&E field as "moderately important" or "very important" for their innovation activities.

Following Cohen et al. (2002, p. 12), only sectors with four or more respondent firms were included in the matrices. Therefore, the number of sectors in each country matrix is smaller than the number of sectors surveyed in the three countries.[2] However, the resulting matrices are about the same size (i.e., 17 S&E fields and 19 sectors in Argentina; 17 fields and 21 sectors in Mexico; and 16 fields and 23 sectors in Brazil).

Argentina

The Argentine matrix shows that the S&E fields most valued by firms for their innovation activities are industrial design, materials and metallurgic engineering, computer science, and agronomy.[3] Out of the 19 sectors, 12 reported at least one S&E field as moderately or very important for more than 50% of the firms, with a total of 15 points of interaction (Table 7.1).

[1] One response had incomplete information and was disregarded.
[2] Number of sectors surveyed: 21 in Argentina; 31 in Mexico; and 27 in Brazil.
[3] S&E fields were classified according to the number of points of interaction of each S&E field with industrial sectors. Another way of classifying them would have been by the last line of the matrix, which shows the percentages of the total number of firms surveyed that mention an S&E field as important. However, such a classification would be biased by the concentration of more than half of respondents in only three sectors.

Table 7.1 Importance of public research by S&E field in Argentina (data are percentages of respondents who indicated research was "moderately important" or "very important")

Industry	N	Agro	CS	FST	Bio	ID	CE	EMM	ME	EE	Mech	CE	Ph	GS	Math	Med	Vet	Chem
15 Food products and beverages	86	48	17	62	14	21	7	10	0	21	22	34	7	2	3	5	12	26
16 Tobacco products	5	80	20	20	20	20	0	20	0	20	0	0	0	0	0	0	0	0
17 Textiles	15	20	33	13	13	53	7	13	0	13	13	40	7	0	0	0	13	33
18 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	38
20 Wood and 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 Paper and paper products	6	0	0	0	0	67	0	17	0	0	0	17	0	0	0	0	0	17

Industry																	
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
24 Chemicals and chemical products	50	16	14	16	24	10	0	4	2	16	14	44	10	0	0	24	8	54
25 Rubber and plastic products	20	0	15	15	0	10	5	15	0	5	15	20	0	0	0	0	0	5
26 Non-metallic mineral products	16	0	13	0	0	25	31	25	38	25	31	31	0	19	0	0	0	13
27 Basic metals	11	0	27	0	0	45	27	55	0	36	27	18	0	0	0	0	0	9
28 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 Machinery and equipment nec	48	21	17	10	0	54	8	48	6	33	48	13	13	2	10	0	0	6
31 Electrical machinery and apparatus nec	17	0	6	0	0	47	12	35	12	47	41	6	0	0	6	0	0	0

Table 7.1 (continued)

Industry	N	Agro	CS	FST	Bio	ID	CE	EMM	ME	EE	Mech	CE	Ph	GS	Math	Med	Vet	Chem
33 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 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 Other transport equipment	5	0	60	0	0	80	0	40	0	0	40	0	0	0	0	0	0	0
36 Furniture; manufacturing nec	4	0	50	0	0	25	0	50	0	25	50	25	0	0	0	0	0	25
All firms surveyed	355	20	18	21	8	30	8	24	4	21	25	26	6	2	3	5	5	19

Notes: Data from RoKS project survey.
nec = not elsewhere classified; Agro = Agronomy; CS = Computer Science; FST = Food Science and Technology; Bio = Biology; ID = Industrial Design; CE = Civil Engineering; EMM = Engineering of Materials and Metallurgy; ME = Mining Engineering; EE = Electrical Engineering; Mech = Mechanical Engineering; CE = Chemical Engineering; Ph = Physics; GS = Geosciences; Math = Mathematics; Med = Medicine; Vet = Veterinary; Chem = Chemistry.

The most-demanded S&E field was industrial design, with four points of interaction: more than 50% of the firms in textiles, paper, machinery, and transport equipment other than motor vehicles reported it was at least moderately important. In addition, firms in all sectors reported links with industrial design to some extent. In second place was the S&E field of materials and metallurgical engineering, which was important for three sectors: basic materials; fabricated metal products; and furniture.

Two industries (furniture, and the manufacturing of transport equipment other than motor vehicles) had more than one point of interaction. They had links to computer sciences, industrial design, materials and metallurgic engineering, and mechanical engineering. However, these were the sectors with the smallest number of respondents, four and five respectively.

Among the sectors with one point of interaction, the strongest links with S&E fields are: food products and beverages with food science and technology; tobacco products with agronomy; paper products and transport equipment with industrial design; tanning and dressing of leather with chemical engineering; chemical products with chemistry; basic metals and fabricated metal products with materials and metallurgic engineering; and machinery and equipment with industrial design.

Three sectors account for more than half of the firms in the Argentine sample: food and beverages (86 firms); chemicals and chemical products (50); and machinery and equipment (48). A closer look at those three sectors is worthwhile. In the manufacture of food products and beverages, 62% of the firms indicated that the S&E field of food science and technology was important, and although not a point of interaction, agronomy was reported to be important by 48% of the firms. In the manufacture of chemicals and chemical products, besides the field of chemistry, reported as important by 54% of firms, chemical engineering was considered important by 44% of the firms. Finally, in the manufacture of machinery and equipment (48 firms), besides the point of interaction with industrial design, the field of mechanical engineering was also reported as important by 48% of the firms. These data show that in the industrial sectors that are important for the Argentine economy there are points of interaction – at least one S&E field is important for the innovative activities of their firms – as well as relevant links with other S&E fields.

Mexico

The Mexican matrix showed 23 points of interaction in 15 sectors (Table 7.2). The S&E fields most demanded by firms were: mechanical engineering (important for eight sectors); electrical engineering (four);

Table 7.2 Importance of public research by S&E field in Mexico (data are percentages of respondents who indicated research was "moderately important" or "very important")

Industry	N	Agro	CS	FST	Bio	ID
15 Food products	53	35.8	24.5	79.2	22.6	28.3
17 Textiles	6	0.0	16.7	0.0	0.0	50.0
18 Dressing apparel; dressing and dyeing of fur	12	0.0	33.3	0.0	8.3	41.7
19 Tanning and dressing of leather; luggage, handbags, saddlery, footwear, etc.	9	22.2	77.8	22.2	44.4	66.7
21 Paper and paper products	8	0.0	37.5	12.5	0.0	37.5
22 Publishing, printing, and reproduction of recorded media	6	0.0	33.3	0.0	0.0	16.7
24 Chemicals and chemical products	59	6.8	16.9	13.6	23.7	16.9
25 Rubber and plastic products	24	0.0	25.0	0.0	0.0	41.7
26 Other non-metallic mineral products	11	9.1	18.2	0.0	0.0	27.3
27 Basic metals	7	0.0	14.3	0.0	0.0	0.0
28 Fabricated metal products, except machinery and equipment	15	13.3	20.0	6.7	20.0	46.7
29 Machinery and equipment nec	24	0.0	20.8	0.0	0.0	29.2
31 Electrical machinery and apparatus nec	23	0.0	26.1	0.0	0.0	26.1
32 Radio, television, and communication equipment and apparatus	7	0.0	14.3	0.0	0.0	28.6
33 Medical, precision and optical instruments, watches and clocks	9	11.1	44.4	0.0	0.0	77.8
34 Motor vehicles, trailers, and semi-trailers	47	0.0	12.8	0.0	0.0	25.5
36 Furniture; manufacturing nec	8	0.0	12.5	0.0	0.0	37.5
52 Retail trade, except of motor vehicles and motorcycles; repair of personal and household goods	5	0.0	60.0	20.0	0.0	0.0
72 Computer and related activities	14	0.0	64.3	7.1	0.0	7.1
73 Research and development	15	13.3	46.7	26.7	33.3	33.3
74 Other business activities	5	0.0	20.0	20.0	0.0	20.0
All firms surveyed	387	8.0	27.1	16.0	10.1	28.7

Notes: Data from RoKS project survey.
nec = not elsewhere classified; Agro = Agronomy; CS = Computer Science; FST = Food Science and Technology; Bio = Biology; ID = Industrial Design; CE = Civil Engineering; EMM = Engineering of Materials and Metallurgy; ME = Mining Engineering; EE = Electrical Engineering; Mech = Mechanical Engineering; CE = Chemical Engineering; Ph = Physics; GS = Geosciences; Math = Mathematics; Med = Medicine; Vet = Veterinary; Chem = Chemistry.

CE	EMM	ME	EE	Mech	CE	Ph	GS	Math	Med	Vet	Chem
11.3	11.3	3.8	18.9	28.3	35.8	15.1	5.7	13.2	15.1	11.3	28.3
0.0	16.7	0.0	16.7	50.0	16.7	0.0	0.0	16.7	0.0	0.0	50.0
0.0	0.0	0.0	0.0	16.7	16.7	0.0	0.0	16.7	8.3	0.0	33.3
33.3	44.4	11.1	55.6	55.6	66.7	55.6	33.3	44.4	33.3	22.2	44.4
0.0	0.0	0.0	37.5	62.5	25.0	12.5	0.0	25.0	12.5	0.0	37.5
0.0	0.0	0.0	50.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.5	16.9	3.4	13.6	20.3	59.3	18.6	5.1	10.2	16.9	10.2	55.9
0.0	4.2	0.0	20.8	33.3	37.5	0.0	0.0	4.2	0.0	0.0	16.7
27.3	45.5	0.0	18.2	18.2	36.4	18.2	9.1	36.4	0.0	0.0	27.3
0.0	57.1	0.0	28.6	28.6	14.3	0.0	0.0	0.0	0.0	0.0	14.3
0.0	46.7	6.7	33.3	53.3	26.7	6.7	6.7	20.0	6.7	6.7	6.7
4.2	41.7	0.0	37.5	54.2	16.7	16.7	4.2	8.3	4.2	0.0	4.2
13.0	30.4	4.3	43.5	47.8	39.1	17.4	4.3	13.0	0.0	0.0	13.0
0.0	0.0	14.3	71.4	42.9	0.0	0.0	0.0	0.0	14.3	14.3	0.0
11.1	22.2	11.1	66.7	44.4	11.1	11.1	11.1	22.2	33.3	11.1	0.0
2.1	19.1	4.3	29.8	66.0	23.4	8.5	2.1	12.8	2.1	0.0	8.5
0.0	12.5	0.0	25.0	50.0	50.0	0.0	0.0	0.0	12.5	0.0	12.5
20.0	0.0	0.0	40.0	20.0	40.0	0.0	0.0	0.0	20.0	0.0	20.0
0.0	7.1	0.0	14.3	7.1	7.1	14.3	7.1	14.3	7.1	7.1	14.3
13.3	20.0	6.7	46.7	26.7	20.0	26.7	13.3	26.7	6.7	13.3	26.7
20.0	0.0	0.0	40.0	20.0	0.0	0.0	0.0	20.0	20.0	20.0	0.0
7.8	19.4	3.4	28.4	37.0	32.0	12.4	4.9	13.4	10.1	5.7	23.8

computer science (three); industrial design (three); chemistry (two); and chemical engineering (three sectors). Other S&E fields with at least one point of interaction were agronomy, mechanical engineering, and physics.

The most pervasive S&E field is mechanical engineering, reported as moderately or very important by firms in seven sectors: textiles; tanning and dressing of leather; paper; fabricated metals; machinery; motor vehicles; and furniture. Electrical engineering was very important for firms in four sectors: tanning and dressing of leather; publishing and printing;

electrical appliances; and medical equipment. Computer science was important for: tanning and dressing of leather; retail trade; and computer and related activities. Industrial design was important for textiles, and leather and medical equipment. Chemical engineering was important for leather, and chemicals and chemical products.

The sector with the most points of interaction was tanning and dressing of leather, which was linked with six S&E fields: computer sciences; industrial design; electrical engineering; mechanical engineering; chemical engineering; and physics. The manufacture of textiles was next with three points of interaction: with industrial design; mechanical engineering; and chemistry. Three industrial sectors had two points of interaction: publishing and printing with electrical and mechanical engineering; chemicals and chemical products with chemical engineering and chemistry; and medical equipment with industrial design and electrical engineering. Another group of ten sectors each had one point of interaction. Some of them revealed a great coherence in their interaction with S&E fields. For example, food products with food science and technology; paper and paper products with mechanical engineering; basic metals with engineering of materials and metallurgy; fabricated metals and machinery with mechanical engineering; electrical appliances with electrical engineering; motor vehicles with mechanical engineering; and computer and related activities with computer science.

Three sectors in the Mexican matrix represented more than 40% of the sample: food products; chemicals and chemical products; and motor vehicles. As in the Argentine case, they all have at least one point of interaction. The manufacture of chemicals and chemical products had 59 respondent firms; 59.3% of them reported that chemical engineering was important and 55.9% reported chemistry. In the manufacture of food products and beverages, 79.2% of the 53 respondents reported that the field food science and technology was important. Finally, 66% of the 47 respondent firms in the manufacture of motor vehicles reported that the field mechanical engineering was important.

Brazil

The Brazilian matrix shows 29 points of interaction in 20 sectors (Table 7.3). The aggregate S&E field of materials, metallurgical, and mining engineering was the most pervasive field with strong links to seven sectors, followed by mechanical engineering and agronomy (four sectors each), and chemistry, computer science, and electrical engineering (three sectors each).

No sector in the Brazilian matrix had more than two points of interaction. This suggests that firms are focused in S&E fields of direct interest

to their research activities. The nine sectors with two points of interaction were: mining (mining engineering and geosciences); food products (agronomy and food science and technology); paper and paper products (chemical engineering and chemistry); coke and refined petroleum products (agronomy and chemistry); rubber and plastics products (materials, metallurgical, and mining engineering, and mechanical engineering); fabricated metals (materials, metallurgical, and mining engineering, and mechanical engineering); computer and electronics (computer science and materials, metallurgical and mining engineering); electrical equipment (electrical engineering and mechanical engineering); and motor vehicles (materials, metallurgical, and mining engineering, and mechanical engineering).

The 11 sectors with only one point of interaction suggest that firms search for the link that is directly related to their R&D activities. Firms in the sector crop and animal production were strongly linked to the field of agronomy. Other links were: chemicals and chemical products to chemistry; non-metallic minerals, basic metals, and machinery and equipment to materials, metallurgical, and mining engineering; electricity, gas, and other supplies to electrical engineering; water collection, treatment, and supply to civil engineering, and telecommunications, computer programming, information activities, and scientific R&D to computer science.

The three sectors with the greatest number of respondents in the Brazilian matrix represented 28% of the sample. However, in contrast to Argentina and Mexico, one of them does not have any point of interaction – pharmaceutical products, with 39 respondent firms. This might be related to the fact that the Brazilian pharmaceutical industry in the last few decades has become mostly a manufacturer of drugs with imported active pharmaceutical ingredients, and has little in-house R&D. Notwithstanding this fact, 45.7% of the pharmaceutical firms report the basic science field of biology as important for their R&D activities. The other two sectors with the most respondents were food products and beverages (32 firms) and electricity and gas (26 firms). The firms that manufacture food products and beverages reported the importance of food science and technology and agronomy. Finally, firms in the electricity and gas sector were strongly linked to electrical engineering.

One last point from the Brazilian matrix: the obvious connections between economic sectors and S&E fields – for example, crop and animal production with agronomy; mining with geosciences or mining engineering; petroleum products with chemistry; and basic metals with metallurgical engineering – are in fact the fruits of long-lasting processes of building relationships between institutions. Those sectors are today among the most important for the Brazilian economy.

Taken together, the three matrices provide clues about scientific

Table 7.3 Importance of public research by S&E field in Brazil (data are percentages of respondents who indicated research was "moderately important" or "very important")

Industry	N	Agro	CS	FST	Bio	ID
01 Crop and animal production, hunting, and related service activities	12	75.0	8.3	16.7	33.3	0.0
02 Forestry and logging	6	66.7	0.0	0.0	16.7	0.0
03 Mining and quarrying	11	36.4	9.1	0.0	18.2	0.0
10+ 11 Food products and beverages	32	50.0	15.6	65.6	28.1	9.4
17 Paper and paper products	6	33.3	0.0	0.0	16.7	0.0
19 Coke and refined petroleum products	6	66.7	0.0	0.0	33.3	16.7
20 Chemicals and chemical products	24	29.2	12.5	12.5	16.7	8.3
21 Basic pharmaceutical products and pharmaceutical preparations	35	11.4	2.9	11.4	45.7	0.0
22 Rubber and plastic products	7	0.0	14.3	0.0	14.3	0.0
23 Other non-metallic mineral products	15	13.3	20.0	0.0	0.0	13.3
24 Basic metals	14	0.0	21.4	0.0	0.0	0.0
25 Fabricated metal products, except machinery and equipment	9	0.0	11.1	0.0	11.1	11.1
26 Computer, electronic, and optical products	22	4.5	54.5	0.0	0.0	9.1
27 Electrical equipment	8	0.0	25.0	0.0	0.0	12.5
28 Machinery and equipment nec	14	42.9	21.4	14.3	0.0	14.3
29 Motor vehicles, trailers, and semi-trailers	8	12.5	0.0	0.0	0.0	25.0
32 Other manufacturing	7	0.0	28.6	14.3	28.6	0.0
35 Electricity, gas, steam, and air conditioning supply	26	19.2	46.2	0.0	19.2	0.0
36 Water collection, treatment, and supply	5	20.0	20.0	0.0	40.0	0.0
43+ 71 Specialist construction activities and architectural and engineering activities; technical testing and analysis	13	0.0	23.1	0.0	7.7	0.0
47 Retail trade, except of motor vehicles and motorcycles	5	0.0	20.0	0.0	0.0	20.0
61+62+63 Telecommunications, computer programming, consultancy and related services and information service activities	22	9.1	72.7	4.5	4.5	4.5
72 Scientific research and development	10	30.0	50.0	30.0	10.0	0.0
All firms surveyed	325	22.2	24.0	11.7	16.3	5.8

Notes: Data from RoKS project survey.
nec = not elsewhere classified; Agro = Agronomy; CS = Computer Science; FST = Food Science and Technology; Bio = Biology; ID = Industrial Design; CE = Civil Engineering; MMM = Materials, Metallurgical, and Mining Engineering; EE = Electrical Engineering; Mech = Mechanical Engineering; CE = Chemical Engineering; Ph = Physics; GS = Geosciences; Math = Mathematics; Med = Medicine; Vet = Veterinary; Chem = Chemistry.

CE	MMM	EE	Mech	CE	Ph	GS	Math	Med	Vet	Chem
0.0	0.0	0.0	0.0	0.0	0.0	8.3	0.0	0.0	25.0	25.0
0.0	0.0	0.0	33.3	0.0	0.0	16.7	0.0	0.0	0.0	16.7
18.2	63.6	27.3	27.3	36.4	9.1	54.5	0.0	9.1	0.0	36.4
9.4	0.0	15.6	12.5	40.6	12.5	6.3	9.4	15.6	34.4	40.6
0.0	16.7	0.0	0.0	50.0	16.7	0.0	16.7	0.0	0.0	66.7
0.0	0.0	0.0	0.0	33.3	0.0	16.7	16.7	0.0	0.0	66.7
0.0	29.2	4.2	16.7	37.5	0.0	4.2	4.2	12.5	8.3	66.7
0.0	5.7	0.0	2.9	28.6	0.0	0.0	0.0	8.6	22.9	34.3
28.6	71.4	14.3	71.4	28.6	14.3	0.0	0.0	0.0	0.0	42.9
40.0	66.7	6.7	6.7	33.3	0.0	0.0	0.0	0.0	0.0	20.0
14.3	85.7	14.3	14.3	21.4	0.0	0.0	0.0	0.0	0.0	0.0
11.1	55.6	11.1	88.9	44.4	22.2	0.0	0.0	0.0	11.1	22.2
4.5	13.6	59.1	18.2	9.1	22.7	0.0	0.0	0.0	0.0	13.6
12.5	25.0	50.0	62.5	25.0	25.0	0.0	12.5	12.5	0.0	12.5
7.1	57.1	21.4	35.7	28.6	21.4	0.0	14.3	0.0	0.0	7.1
0.0	50.0	12.5	62.5	25.0	12.5	0.0	0.0	0.0	0.0	0.0
0.0	42.9	0.0	42.9	14.3	14.3	0.0	0.0	14.3	0.0	0.0
26.9	19.2	84.6	46.2	23.1	23.1	19.2	7.7	3.8	0.0	15.4
60.0	40.0	40.0	40.0	20.0	20.0	20.0	20.0	0.0	0.0	20.0
61.5	15.4	23.1	0.0	7.7	0.0	23.1	7.7	0.0	0.0	0.0
0.0	20.0	0.0	20.0	0.0	0.0	0.0	0.0	0.0	20.0	20.0
4.5	9.1	36.4	13.6	0.0	13.6	0.0	13.6	0.0	0.0	0.0
10.0	10.0	40.0	20.0	20.0	20.0	30.0	0.0	10.0	30.0	20.0
12.6	25.8	22.8	22.8	23.4	10.5	7.4	4.9	4.9	8.9	24.3

capabilities and production specialization in Latin American countries. The S&E fields most in demand by firms were predominantly engineering fields, which accounted for about half of the points of interaction. Other applied science fields required by firms were computer science, industrial design, and agronomy. In the basic sciences, only chemistry had connections with firms.

This pattern of demand for S&E fields reflects production specialization in the region. The industries that concentrated most points of interaction in the three countries were predominantly low- and medium-tech industries (e.g., leather products, textiles, furniture, food products, paper, metals, chemical products, motor vehicles and other transport equipment, and machinery and equipment). Computers and electronic goods were the only medium- to high-tech industries with significant links to S&E fields.

LATIN AMERICAN MATRICES COMPARED WITH THE US MATRIX

When compared with the US matrix, the three Latin American matrices showed significant differences. The matrices were compared in two ways: a quantitative discussion of the six topics shown in Table 7.4, and a qualitative review.

For comparative purposes, it is important to point out the methodological differences between the US matrix and those from Latin America. The size of the matrix was different – the US matrix had more sectors and fewer S&E fields than those for the Latin American countries. The Latin American matrices included some S&E fields that were not in the CM survey (e.g., mining engineering, agronomy, food science and technology, geosciences, industrial design, and veterinary science). These fields were

Table 7.4   A comparison of the main features of the matrices from the US, Argentina, Mexico, and Brazil

Feature	United States	Argentina	Mexico	Brazil
Size of matrix (sectors x S&E fields)	34x10	19x17	21x17	23x16
Number of respondent firms	1252	355	387	325
Points of Interaction (PIs)	47	15	23	29
Zeros (matrix cells with 0%)	19	136	112	144
Sectors without PIs	8	7	6	3
S&E fields without PIs	2	9	8	6

Source: Based on Cohen et al. 2002, p.11, and Tables 7.1–7.3.

included because of their importance to sectors such as mining, agro-food industries, and crop and animal production, which have a strong presence in Latin American countries. There were also differences in sectors. The CM survey deals only with manufacturing sectors, whereas, in the Latin American matrices (except for Argentina), other economic sectors were included to account for differences in economic specialization. The Argentine matrix includes only manufacturing industries.

The number of firms surveyed is consistent with the size of the economies (US with more than 1000 firms; the Latin American countries with fewer than 400 firms). The number of respondent firms in the Latin American surveys reflected different approaches in the field work (Arza and Vázquez 2010; Dutrénit et al. 2010b; Fernandes et al. 2010). One important difference in the samples for each country was the general selection criterion. In the US, the starting point was a database of firms that had invested in R&D; whereas, in Latin America, the starting point was data about firms that were cooperating with universities and research institutes.

There were differences in the importance attributed by firms to public research by S&E fields in Latin America and the US. The differences probably reflect the more diffuse nature of public research in the national system of innovation (NSI) in the US when compared with the more concentrated links between economic sectors and S&E fields in NSIs in developing countries. This point is strengthened by comparing the number of zero cells in the US matrix (Cohen et al. 2002, p. 11) with the number of zeros in the matrices for Argentina, Mexico, and Brazil (Tables 7.1–7.3). In the US matrix, 5.6% of the cells were zero, whereas, in the Latin American matrices, zero cells ranged between 31% and 42%.

The combined evaluation of points of interaction and zeros within these matrices provided an overall picture. The US matrix presented a larger number of points of interaction (47), whereas the number of cells with zeros (no respondent firm of the sector reporting any importance to a specific S&E field) was larger in the Latin American matrices (from 112 in the case of Mexico to 144 in Brazil versus only 19 in the US). In other words, in the US the industrial sector as a whole was more connected with the scientific infrastructure, or those connections seemed to be more widespread. In the case of Latin American countries, these connections seemed to be more concentrated than in the US.

This specific feature can also be seen in the last two lines of Table 7.4. A proportionately higher number of sectors had no points of interaction in the Latin American matrices than in the US matrix. In the same way, almost half of the S&E fields had no point of interaction with economic sectors in Latin American matrices, whereas, in the US matrix, only two out of ten fields had no points of interaction. Even if only the S&E fields

that were common to both the US and Latin American matrices are considered, five out of ten do not have points of interaction in the Argentine matrix and four out of ten do not have points of interaction in the Mexican and Brazilian matrices.

Looking at the points of interaction from a qualitative point of view, the three Latin American matrices showed that even in so-called low-tech and medium-tech sectors (e.g., mining, pulp and paper, refined petroleum, basic metals, and food products) firms considered S&E fields as important for their innovative activities. This is a relevant difference with the US, which had no points of interaction in any low- and medium-tech industrial sector (e.g., textiles, basic chemicals, steel, metal products, special purpose machinery, and electrical equipment). In the Latin American countries, the two sectors related to metals (basic and fabricated metal products) had points of interaction. Therefore, one important point of contrast was that medium-tech sectors did not have points of interaction in the US, but did in the NSIs of developing countries such as Argentina, Mexico, and Brazil.

Industrial sectors such as pharmaceutical products (in Brazil) and medical instruments (in Argentina) did not have points of interaction, whereas in the US they did. Therefore, another important point of contrast was that high-tech sectors, such as drugs and medical instruments, had points of interaction in the US but did not have them in Brazil (drugs) or Argentina (medical instruments).

It is important to look at the three Latin American matrices with regard to basic sciences. Chemistry was the only basic science that had points of interaction in all three countries: one in Argentina; two in Mexico; and three in Brazil. Furthermore, in Argentina and Mexico one of the largest manufacturing sectors (chemicals and chemical products) considered biology as important for more than 23% of the firms. This is remarkable because Cohen et al. (2002) noted a dual role for basic sciences: they were an important input for applied sciences and they were also useful for firms in specific sectors. The US matrix showed more basic science fields with points of interaction (the US matrix showed many more interactions than the Latin American matrices). Therefore, basic sciences seemed to be more directly useful for industrial innovation in the US than in Latin America. Because there were more points of interaction between basic science fields in the US matrix (e.g., biology with drugs; physics with semiconductors; and chemistry with petroleum, chemical products, plastics, and drugs), this might also have been related to the structure of US industry: the points of interaction of some basic sciences were more directly related to high-tech sectors (e.g., drugs and semiconductors). In the Latin American countries, those high-tech industries may not yet be powerful enough to innovate, or they may

be dominated by foreign-owned firms that do not innovate within their subsidiaries. That is why in Brazil it is not surprising that there were no points of interaction between drugs and biology or chemistry. The main conclusion regarding basic sciences was that in Latin America they fulfil the dual role indicated by Cohen et al. (2002, p. 10) – they are important as sources for applied sciences and engineering, and they already show some points of interaction.

HISTORICAL ROOTS FOR POINTS OF INTERACTION

The final step is to investigate the historical roots of some existing points of interaction in Argentina, Mexico, and Brazil. The objective is to check the extent to which historical relationships between S&E fields and firms support each point of interaction.

The historical roots of these interactions during the formation of the United States' NSI were presented in the Introduction to this book. Therefore, the snapshot captured by Cohen et al. (2002) may be understood as the end result of a long historical development.

In Latin America, economists and historians also have pointed out similar trends in the formation of long-standing relationships between S&T in successful economic sectors – the same ones for which the Latin American matrices showed strong links between S&E fields and firms. Furtado (1970) provides some examples of those relationships: (1) a very important mining and metallurgical experience in Mexico; (2) the processing of agro-products as the initial nucleus of industrialization in Argentina; and (3) industrialization in Brazil during the government of Vargas, which, because of the high cost of imported components, stimulated local engineers to provide creative solutions. Furtado (1982, p. 23) also mentions the Instituto de Pesquisas Tecnológicas (IPT) in Sao Paulo and its support to the metal industry. With this background, we will now discuss how research institutes and universities have been involved with these sectors.

In Mexico, the Escuela de Minería was founded in 1792 (Guedea 2000, p. 281). This focus on mining had later impacts, as stated by Riguzi (1990, p. 537): "within the *Escuela Nacional de Ingenieros* . . . there is a concentration of professional skills related to mining."[4] This is related to the initial phase of Mexican industrialization. According to Furtado

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[4] Besides the dominance of mining engineers in 1883, Riguzi (1990, p. 542) notes that by 1908, during the "Mexicanization" of railways, there were Mexican engineers with these skills.

(1970, p. 103), "the new phase of development of the export mining industry, based on the expansion of world demand for industrial metals, was centered in the northern part of the country." Furtado suggests that, "in countries exporting primary products, the initial phase of development was influenced by the nature of the products exported. . . Thus . . . the processing of minerals was an important sector of Mexican industry. This explains how Mexico gained the metallurgical experience that was to play a key role in the country's industrial development" (Furtado 1970, pp. 105–106). These historical roots may be supporting the "mining cluster" described by Casas et al. (2000, p. 165). In their evaluation of university and industry relations, Casas et al. (2000) describe the "complexity of regional configurations":

> This is the case of the mining sector cluster in the Northeast of the country which, although its original nucleus is at the State University of San Luis Potosi and the mining industry in that state, it is expanding toward other states in the region that have mineral resources. It involves other mining companies and (institutions) such as the Instituto Tecnológico de Saltillo and CINVESTAV (Centro de Investigaciones y de Estudios Avanzados del Instituto Politécnico Nacional), both located in Coahuila. (Casas et al. 2000, p. 165)

Chemistry is another field rooted in the Escuela de Minería that contributed to the development of both a strong scientific community and an important chemical industry. Chemical processes are at the base of the leather and footwear industry, but recently this industry was enriched by a multidisciplinary approach by a specialized research centre that integrated nanotechnology, biomedical, and electronic engineering projects. These projects combine basic and applied research, including physics, mathematics, and materials science.

In Argentina, Furtado (1970, p. 105) mentions that "the processing of agricultural and livestock products for both export and home market was the original nucleus of modern Argentine industry." In 1956, the Instituto Nacional de Tecnología Agropecuaria (INTA) was created, an institute that "promoted the participation of private industries of seeds and agrochemicals products" (Hurtado 2010, p. 97). The long historical roots of the points of interaction identified in the Argentine matrix (Table 7.1, agronomy, and food science and technology) may be tracked to the creation of INTA, but also to earlier processes, because INTA was based on 28 experimental stations that were created starting in 1910 (Hurtado 2010, p. 95). León and Losada (2002) describe these pre-existing agro-related research institutes and their dates of creation: Instituto de Suelos (1943), Instituto Microbiologia (1944), and Instituto Fitotecnia (1945). There were also, according to León and Losada, investigations related to agri-

cultural and livestock products, such as the immunological investigations made by the Instituto Agronómico de Santa Catalina (during the 1930s) and the activities of the Facultad de Agronomía de Buenos Aires (during the 1940s). According to León and Losada (2002, pp. 37–38), in 1954 the agricultural institutes that were the base for the formation of INTA employed 235 researchers and technicians. León and Losada (2002, p. 42) highlight that the experimental stations, even before the formation of INTA, had research results that were used to improve the production of grain after 1950.

In Brazil, the first business ventures in iron production date from the early 19th century, but it was not until the Escola de Minas – Ouro Preto (EMOP) was founded that production began to increase in scale. The creation of EMOP was inspired by Emperor Pedro II's 1872 visit to the École Nationale Supérieure des Mines de Nancy, which he used as a model, and by his contact with Auguste Dubrée, Director of the Paris School of Mines, whom he invited to head the future school in Brazil. Unveiled in 1876, EMOP exerted growing influence by training geologists, mining engineers, and metallurgical engineers. Between the late 19th and early 20th century, these professionals contributed to the creation of geographical and geological institutions and to the mapping of iron ore reserves in Brazil. Their studies and research located and measured large reserves of high-content iron ore, and in 1910 their discoveries were presented at an international conference in Stockholm, which attracted foreign companies to develop the reserves (Schwartzman, 1979, Appendix; Suzigan and Albuquerque 2011, p. 24). Several projects bore fruit, and gave rise to the first steel mills in Brazil in the 1920s. But the decisive boost was the creation of Companhia Siderúrgica Nacional (CSN) and Companhia Vale do Rio Doce (Vale) during World War II, followed by public policy to accelerate industrialization in the post-war years.

However, one of the most important factors that explains the current success of Brazil's mining and steel industries is the rich experience of interaction between firms and the Departamento de Engenharia Metalúrgica e de Materiais, Universidade Federal de Minas Gerais (UFMG).[5] After UFMG created a graduate course in metallurgical and materials engineering in 1973, its researchers discovered the industry's difficulties with imported technology and proposed collaboration with firms to diagnose the problems and offer solutions. The collaboration, funded by Financiadora de Estudos e Projetos (FINEP), started with the creation of technological extension courses and was later extended

[5] For a detailed account of this experience, see Paula e Silva (2007).

to include graduate programmes run jointly by firms and the university. Between 1975 and 2006, the department awarded 256 Master's degrees in metallurgical engineering to employees of 36 firms, and 20 Doctoral degrees to employees of ten firms, all in mining and steel production. Several of the Master's dissertations and Doctoral theses contributed important knowledge that was motivated by the search for solutions to the real problems faced by firms, and generated patents and technological innovations in processes and products. Among the technological problems solved were: development of steel plates that harden in the process of baking, then dominated by Japanese steel firms; thermal treatment of steel plates in continuous rolling mills; development of materials with greater wear resistance by substituting niobium for molybdenum; development of electrical and magnetic steels; development of stainless steel alloys for ethanol-fuelled engines; development of metals that are sensitive to light; and development of coloured stainless steels.

The firms in the mining and steel industries that interacted with the Departamento de Engenharia Metalúrgica e de Materiais are today the most competitive in international markets: Vale (mining); Acesita (special steel); and CSN, Usiminas, Cosipa, and Açominas (steel). Production and exports soared from the late 1970s, and Brazil is today one of the largest producers and exporters of ore and steel in the world.

Although very schematic, these three historical examples confirm our argument that a long-standing co-evolutionary process of relationships between research institutions and firms lies behind each successful case of UIL in Latin America. The matrices relating S&E fields to economic sectors in Argentina, Mexico, and Brazil show three examples of points of interaction. They also indicate other points of interaction with strong links between S&E fields and economic sectors, which could be the object of case studies in future research.

Matrices of interactions between S&E fields and economic sectors are a useful research tool. By identifying points of interaction, and by pointing out weak UILs, they help us to understand the specifics of S&T relationships in developing countries.

MATCHES AND MISMATCHES DURING PHASES OF INDUSTRIALIZATION

Matrices of interaction are a snapshot of existing relationships between S&E fields and economic sectors. This chapter explored the adaptation of a research tool developed for the US for use in three developing countries in Latin America. This adaptation was useful both for assessing the

relationships between S&T in the three countries, and for comparing their pattern of relationships with those in a developed economy.

The comparison led to expected findings: the number of points of interaction was larger in the US matrix, whereas there were fewer in the matrices of Latin American developing countries. But the comparison also provided unexpected findings. For example, low- and medium-tech sectors had points of interaction with S&E fields in all three Latin American countries. This finding ran against conventional wisdom that seems to underestimate the role of universities and research institutes during development. The matrices help to show the sectors in which universities and research institutes are now important, and also indicate the challenges of advancing toward high-tech industries.

These findings led to the exploratory investigations of the historical roots of some of the identified points of interaction. Such investigations for the three Latin American countries (and this seems to be the case in South Africa as well; see Pogue 2006) showed how successful cases were built in a long-lasting historical process – a corollary of this finding is that behind each successful point of interaction is a university or research institute. This finding helps to prepare a line of investigation that would integrate the processes of industrialization with the processes of institution building for universities and research institutes in Latin America. This line of inquiry might also help evaluate the historical roots of NSIs in Latin America.

The matrices for Latin American countries indicate where the matches are between S&T. But they also indicate important mismatches or misalignments. By identifying mismatches, the matrices may help in at least two ways. First, they show important sectors for technological catch up that do not have points of interaction – the high-tech sectors. This lack of points of interaction is an important subject for research, because it is clear that these sectors could benefit from interactions with specific S&E fields. Second, the matrices show how S&E fields with pervasive influence on economic sectors are still not well developed. One limitation of these matrices is their inability to show S&E fields that are domestically strong, but do not interact with specific economic sectors. To identify such mismatches, the matrices can be used to organize comparisons with investigations focused on the identification of S&E fields that are important locally (e.g., statistics on the distribution of scientific papers per S&E fields, and statistics on the distribution of research resources by S&E fields). Both findings have implications for public policies.

The road to development in Latin America needs more intense interaction between S&T, which means policies are needed to increase links between S&E fields and firms. This approach implies that such policies

must deal with both private firms (that need to improve their absorptive capabilities) and public research organizations (that must both deepen the quality of their research and broaden their fields of activities).

The identification of matches and mismatches may provide a focusing device to help strong, strategic industrial sectors obtain a deeper scientific basis, and to integrate strong S&E fields into industrial policies aimed at entry into new economic sectors.

Finally, this chapter shows that comparisons between matrices for different countries is feasible, and suggests that such matrices of UILs may be a tool that should be expanded and more systematically prepared. With an inter-temporal series of matrices, it would be possible to improve our present understanding of how development might take place in Latin America. Comparisons with Asian and African countries would also further improve global understanding of the formation of NSIs.

PART III

Toward a framework of global interactions
between universities and firms

8. Global interactions between firms and universities: a tentative typology and an empirical investigation

Leonardo Ribeiro, Gustavo Britto, Glenda Kruss, and Eduardo Albuquerque

In a world where the tension between "national systems of innovation" (NSIs) and "transnational technology" (Nelson and Rosenberg 1993) has increased so much, that it is necessary to rephrase questions about local interactions between firms, farms, and universities across the world, interactions might be seen within a context shaped by the beginnings of a global innovation system.

Throughout the whole research process, our teams found diverse indications of the importance of international flows and connections. Eun et al. (Chapter 4, this book) show the links between recently formed start-up companies and foreign universities – probably indicating the recent links between foreign-trained young Chinese scientists and their former supervisors and departments. In Thailand, foreign-owned suppliers are the third most important external source of collaboration for product innovation (Intarakumnerd and Schiller 2009, p. 562), and a global player like Seagate "set up a joint training programme with five Thai universities" (Intarakumnerd and Schiller 2009, p. 578). In Malaysia, our research team surveyed 150 firms from the electronics sector, in which 53.7% are foreign-owned firms (Rasiah and Govindaraju 2009, p. 536, and personal communication with the authors, 10 May 2013). Kruss et al. (2012, p. 527) mention how in South Africa the contact of biotechnology firms is mainly with foreign firms. Adeoti et al. (2010, p. 102) describe how Nestlé in Nigeria works with the Federal University of Agriculture, Abeokuta (UNAAB) and contributes to its improvement.

The importance of foreign-owned firms in all four countries investigated by our Latin American teams is stressed by Dutrénit and Arza (2010, p. 544). In the Brazilian survey, 32 subsidiaries answered the questionnaires (12.8% of the firms). This finding was so important that a special investigation of the similarities and differences between domestic

and foreign firms was prepared (Silva Neto et al. 2013). This study showed that, as foreign firms become embedded in the existing NSI, they behave in a similar way to domestic firms.

All those encounters with international flows – more specifically, with interactions between firms and universities that jump national boundaries – pushed our research one step further to ask: How can we deal with these interactions in the global context? The intersection between our research and another international investigation led by Jo Lorentzen (the Impact of Networks, Globalisation, and their Interaction with EU Strategies [INGINEUS] Project) gave us the opportunity, resources, and focus to begin to answer this new challenge. The starting point of the INGINEUS Project was the elaboration of Global Innovation Networks (GINs) – networks that included international interactions between firms and universities.

This combination of research projects led us to consider two rich strands in the literature. These are: (1) the literature on global innovation networks (e.g., Ernst 2006), which focused on international connections but placed little attention on networks that involved firms and universities, and (2) the literature on interactions (e.g., Klevorick et al. 1995), which placed too much attention on interactions without taking a closer look to the international dimension. These two strands provide a fertile ground on which to deal with interactions in a global context.

INTERACTION WITH UNIVERSITIES AND GINs

Although two strands of the literature on innovation (interactions and GINs) mention universities and foreign corporations, neither conceptualizes these two concepts in a systematic manner as a core research focus. This section evaluates how each strand of the literature on innovation deals with the issue that is not at its core – how the literature on the interactions of firms with universities deals with the globalization of research and development (R&D), and how the literature on GINs deals with the role of universities.

References to Universities in the Literature on GINs[1]

The literature on GINs definitely displays awareness of the significant relationship between GINs and universities and research institutes, but this is typically implicit and largely unexplored. In the earliest literature, elaboration of the external partners that collaborated with global

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[1] This section is based on Britto et al. (2013).

companies in their R&D processes included universities alongside customers, suppliers, alliance partners, and joint-venture partners. Kuemmerle (1997) pointed to foreign universities as targets for "home base augmenting" foreign R&D. A survey of 300 executives highlighted the significance of universities and educational establishments, which were reported as the most frequent collaboration partners for 60% of respondents (The Economist Intelligence Unit 2007, p. 10).

Likewise, an OECD (2008b) report aimed to show how the use of external sources of technology was increasing and went hand in hand with global innovation networks. Universities and research institutes were identified as critical sources of innovation, and seen as evidence of a growing trend toward the globalization of industry–science relationships. One mechanism was the establishment of units to identify potentially interesting R&D at universities. Another was new financial arrangements, corporate venture-capital divisions, to access new ideas through joint ventures, acquisitions, or university-based collaboration. At least three out of six reasons for major companies to invest in R&D in China were related to universities – the pool of talent available, the pursuit of private funding sources by universities and research institutes, and the possibilities of accessing new innovations and entering into intellectual property rights (IPR) agreements (UNCTAD 2005).

The shift from in-house, centralized R&D units to strategic alliances with other firms or universities was stronger in certain sectors, such as pharmaceuticals, because a single company cannot have expertise in all the research areas required to develop new products (UNCTAD 2005). The literature is replete with examples from other sectors. Examples of collaboration between foreign affiliates and local universities include: Microsoft Asia in partnerships with Chinese universities; Intel, which reports 250 sponsored research projects; and STMicroelectronics, which has a training centre in Rabat, Morocco (UNCTAD 2005). Examples of Asian firms that have established GINs with universities in the US and Europe include China's Huawei (Ernst and Naughton 2008) and the Taiwan Semiconductor Manufacturing Corporation (TSCM) (Ernst 2009). Type three of Ernst's (2009) taxonomy specifically mentions universities only with regard to the GINs of these Asian firms. Of course, in the two first types (intrafirm and interfirm), the direct and indirect links with universities are implicit, given the previous formulations of Dunning (1993) and Kuemmerle (1997) that were incorporated into Ernst's elaboration. Ernst's type four GIN, international public–corporate R&D consortia, is not well elaborated or exemplified, but it has strong parallels with the category of "internationalization of innovation" that involves universities, public research centres, national firms, and multinational enterprises

(MNEs) (UNCTAD 2005). It is not difficult to identify actual examples, such as EUCAGEN (the International Eucalyptus Genome Network), which involves 82 public and private institutions, including the Brazilian firm Fibria (Penchel 2008).

References to International Networks in the Literature on Interaction

In contrast, Ernst (2002) highlighted the shift toward the decentralization of R&D in the last few decades, and criticized the literature on NSIs for its neglect of the international dimension. Other papers on the internationalization of NSIs recognize this limited focus beyond national boundaries (Carlsson 2006). The criticism is valid, but somewhat overstates the case. If we read the literature on NSIs carefully, we find research on internationalization, even if the authors emphasize the relatively slower trend toward the globalization of technology, when compared with finance and production (Cantwell 1995; Patel 1995).

If we look closer, we can find important clues to the relevance of the international dimension – at least implicitly. Science is international by definition (Zitt and Bassecoulard 2004). Catch-up processes highlight the importance of international contacts and access to foreign knowledge. Every description of a successful catch-up process necessarily deals with flows of foreign technology and science. A re-read of Nelson (1993) shows how each country – when it emerged to take technological leadership – designed creative ways to access and use knowledge available elsewhere. Students sent abroad, engineers invited to create faculties, foreign engineers hired to run new firms, factories bought, and visits to top firms and top universities – many different ways were designed to absorb knowledge available elsewhere.

Other research suggests that changes in the international scenario impacted the fate of important NSIs – for example, the case of the US after post-war European and Japanese catch up (Nelson and Wright 1992). MNEs also matter (Chesnais 1988, 1994). Studies of international alliances, production, and cooperation show how connections between different NSIs are established (Ostry and Nelson 1995; Hagedoorn 2002; Pietrobelli and Rabellotti 2011).

Scientific infrastructure may be an important attractor of foreign firms (Pavitt 1991). In an investigation of foreign R&D by US MNEs, Patel (1995) found that the firms that most internationalized their R&D were in the beverage and tobacco, food, building materials, other transport, pharmaceuticals, and mining and petroleum sectors. Except for pharmaceuticals, these are not sectors typically characterized as high tech, nor are they typically associated with a global mandate. Most R&D activities related to localized adaptation were designed to take into account differences in

consumer tastes and government regulations, or to exploit local natural resources. Patel proposed that the firms with higher R&D intensity were internationalizing technological activity to a lesser extent, because production and R&D were required to be in close proximity to each other.

Patel's research is a useful identification of changes over time. Since 1995, as Ernst (2002) has suggested, there has been a rise of internationalization of high-tech sectors. Furthermore, Patel (1995) pointed to specific reasons for the internationalization of R&D in sectors like food, mining, and petroleum. As time goes by, the nature of foreign R&D activities becomes more complex.

The investigation of this growing complexity even begins to mention "global systems of innovation." There are at least two different ways to suggest this new stage of innovation systems. The first is developed by the literature on specific high-tech products that are manufactured in global production chains. Examples of papers that explicitly mention global innovation systems are an investigation on the flat-panel display industry (Spencer 2003) and on Apple's iPod (Linden et al. 2007). The second approach to the concept of global innovation systems is through attempts to deal with "world-level challenge," such as climate change: Cozzens and Catalán (2008, p. 3) review the literature on diverse levels of innovation systems (national, regional, and sectoral) and suggest a new variety – "global systems of innovation," "a multi-level network of diverse actors" that "interacts to address a world-level challenge, accumulating knowledge across national borders and developing, testing and adopting new approaches." Both references to "global systems of innovation" deal with actors that at least explore capabilities dispersed across different NSIs. Therefore, the focus on the international dimension of NSIs is conceptually possible.

A TENTATIVE SYNTHESIS: GLOBAL INTERACTIONS BETWEEN FIRMS AND UNIVERSITIES

The arguments presented earlier suggest that GINs have not one, but two main drivers. First, the MNEs, and their growing capabilities, technologies, and locational diversity move across the world selecting locations and distributing productive and innovative labour. Second, the formation and growing complexity of NSIs, especially at the periphery, is a process that goes far beyond the limited push of capital toward new regions and sectors. One important engine of this process is the internationalization of science. The formation of NSIs involves political forces that shape states and their autonomy, capabilities, and public resources to generate and

support their public institutions. For example, the rise of talent pools is a consequence of investments in science and engineering that shape NSIs. Therefore, two movements are reshaping and reorganizing the international division of labour. This reshaping of the international division of labour, in turn, affects the internal decisions of MNEs and the actions of their subsidiaries, and further pushes changes in the international division of innovative labour.

The combination of these two drivers leads to a complex picture, in which the nature of NSIs matters for the formation of networks, their main characteristics, and the nature and scope of the international hierarchies that are established.

A tentative framework to synthesize these insights is suggested in Figure 8.1. Firms (local and MNEs), universities, and their links, are reflected in a hierarchical world, divided between a centre and a periphery (Furtado 1982). The implicit social and political forces that shape NSIs
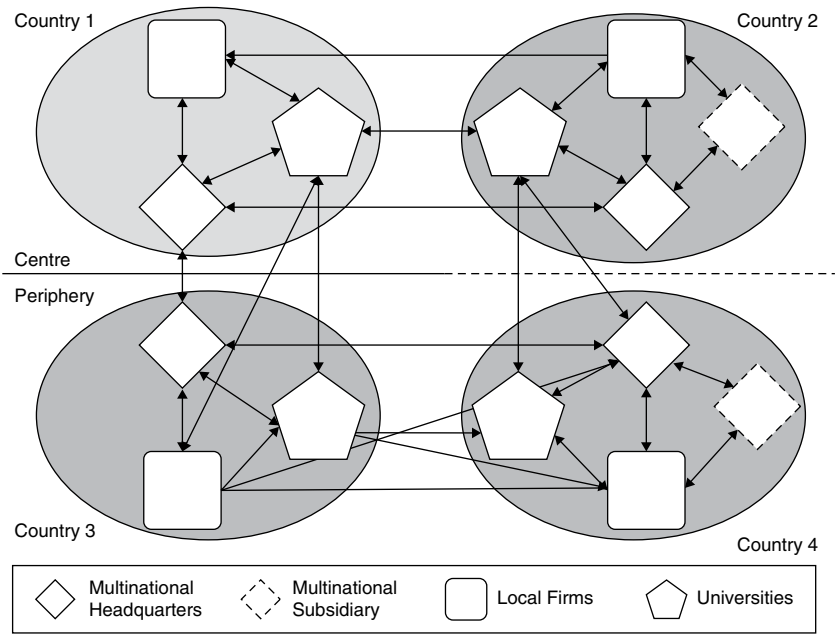
Figure 8.1   Tentative framework for global interactions between firms and universities

define the major characteristics of the countries and their possibilities within a global innovation system.

Figure 8.1 reflects a division between the centre and the periphery. But this divide has two features: the first is portrayed as a solid line; the second as a broken line. This difference expresses graphically the possibility of catch up – the emergence of a country that successfully overcomes under-development (i.e., crosses the broken line). South Korea during the 1980s and 1990s is a case in point.

The starting point is work that conceptualizes the interactions between firms and universities in developed countries, based on interactions within a single country (Klevorick et al. 1995; Cohen et al. 2002). These are reflected within country 1 in Figure 8.1. This work has been elaborated to examine the interactions between firms and universities in developing countries (interaction within national boundaries), but which may include subsidiaries of MNEs in those countries (Rapini et al. 2009; Lee et al. 2009; Kruss 2009b). These are reflected within country 3 in Figure 8.1.

A similar limited set of interactions was suggested by Patel and Pavitt (1998), who were very cautious on the internationalization of innovation. They stressed the ways in which firms in developed countries may use the scientific infrastructure of other countries as sources of information, if their national systems are not able to meet the needs of innovating firms. These are represented as interactions between MNEs in country 2 and universities in country 1 or vice versa.

A critical work that links the two strands is the UNCTAD (2005) study that demonstrates the chain of MNE connections between developed and developing countries (linking countries 1 and 3 in Figure 8.1). The taxonomy of GINs, specifically types 1 and 2 (Ernst 2009), further informs the elaboration of these links between countries 1 and 3.

Ernst's (2009) discussion of a type 3 GIN, of an MNE based in a country at the periphery and interacting with universities at the centre, informed the elaboration of the framework. This is reflected in the connections between an MNE with headquarters in country 3 or 4, its subsidiaries in country 2, and universities in country 1 or 2. Likewise, Azevedo (2009) analysed a transnational firm based in a peripheral country that had research collaboration with 70 universities and research centres abroad (a firm from country 3 interacting with universities in countries 1 and 2 – or multiple countries at the centre).

OECD (2008c) research on Japanese MNEs and their networks with universities in China, India, Japan, and the US illustrates a different set of possible connections between MNE headquarters, MNE subsidiaries, and universities. These are reflected as connections between countries 1 and 2 and between country 1 and countries 3 and 4 in Figure 8.1.

The literature also highlights a growing trend toward connections between firms based in different countries at the periphery (e.g., biotechnology interfirm networks (Thorsteinsdóttir et al. 2010). These firms are typically born as spin-offs from local university research, with their international connections. They are represented as connections between the local firms in countries 3 and 4.

The significance of connections between the universities – the science networks – is also included in the framework. There are strong "engines of internationalization" of science (Zitt and Bassecoulard 2004). For developing and catch-up countries, the networks of science, and related educational investments, are often the first networks to be established to connect one country with the global knowledge networks centred in the leading countries. Examples are global research consortia such as the International Human Genome Sequencing Consortium, which includes research institutes from China, France, Germany, Japan, UK, and US. It is important not to underestimate these scientific networks. They connect all four countries in Figure 8.1.

Supported by this literature, Figure 8.1 is a tentative framework to deal with global interactions between firms and universities. This framework yields four main types of interaction, with variations depending on their location in the centre or periphery:

Type 1: LOCAL firms interacting with local and foreign universities
    (a)   in the North
    (b)   in the South
Type 2: MNEs interacting only with their LOCAL home-based universities
    (a)   in the North
    (b)   in the South
Type 3: MNEs interacting both with LOCAL home-based universities and FOREIGN universities in host countries
    (a)   from the North
    (b)   from the South
Type 4: INTERNATIONAL consortia between firms and networks of universities.

Type 1: Only Local Interactions

These interactions between local firms and local universities do not involve cross-border transfer of knowledge. It could represent the first step by a firm to become transnational. That is, it allows for an initial accumulation of knowledge and capabilities that supports a transition from a local to a

transnational firm, because there is a deep correlation between transnationality and R&D intensity (Caves 1996). In Figure 8.1, these interactions are represented as the relationships between firms and universities within each country. In earlier stages of capitalism at the centre, they could be typical advanced interactions with universities. This type of interaction can also be located in firms at the periphery – within countries 3 and 4.

Interactions between local firms and foreign universities are the first and simplest form of cross-border transfer of knowledge. In Figure 8.1, this flow would connect a local firm in country 1 with a university in country 2. Local firms would typically interact both with universities in their home countries and with foreign universities. Historically, this type of interaction would first connect developed countries (countries 1 and 2). This type of interaction is important for local firms at the periphery looking for knowledge that the local science infrastructure is not able to provide. In Figure 8.1, this interaction is represented as a connection between a local firm in country 3 and a university in country 1.

Type 2: Transnationals Interacting Only with Home-country Universities

This would be the typical relationship reported in the literature on internationalization of R&D. The MNEs have connections with their home-country universities, but either the host countries do not have R&D activities or the R&D activities are completely centralized at the MNE headquarters.

Type 3: Transnationals Interacting Both with Home-country and Host-country Universities

This is the most recent pattern of interaction. There is a broader division of innovative labour within the MNE, with the possibility that a subsidiary assumes contacts and performs contracts with the host-country university. The nature of this relationship will depend on the nature of the subsidiary's role within the MNE – ranging from limited adaptive activities (that would require contacts with local laboratories or engineering departments) to more advanced projects (that would involve joint R&D research with local universities, sometimes in connection with foreign universities). The hierarchy and decision making about the specific roles of home-country and host-countries R&D departments may vary greatly, and this variety should be incorporated within this type of interaction.

Firms (local or transnational) may establish contact with one specific university (local or foreign), but they would take advantage of other universities (local or foreign) that are linked to the first university through

their existing scientific and educational links. This is important, given the natural trend to the internationalization of science through its formal and informal links. The interactions of firms with networks already established among universities are rich in multidirectional knowledge flows.

Type 4: International Consortia between Firms and Universities

This type of interaction involves firms, universities, and research institutions, but might be proposed and coordinated by the academic side of the interaction. Intergovernmental cooperation and international institutions, such as the World Health Organization (WHO), could trigger this kind of interaction. They could be "mission oriented" and necessarily nonhierarchical. They could also be characteristic of a global innovation system.

A fifth type is possible, but does not yet exist – a nonhierarchical network between MNE headquarters and subsidiaries, and their connections with universities. Asymmetry and hierarchy are defining characteristics of both previous global production networks (GPNs) and existing GINs (Ernst 2009, p. 15). This type of interaction must be included to benchmark prevailing international networks – it could be seen as a desired feature of a global innovation system, and poses a challenge to policy.

These four main types of interaction are depicted in the framework, but it certainly does not cover all possibilities. Many real-world cases would be mixed cases. For example, the formation of international networks that may combine interactions at MNE headquarters that have interfirm connections with local firms in a foreign country, and these local firms may have interactions with local universities. Another example is an MNE that establishes contacts either with foreign universities in countries where it does not have a subsidiary, or directly with a foreign university, bypassing its local subsidiary.

There are two differences with Ernst's taxonomy that deserve comment. First, the taxonomy elaborated here does not differentiate the home country of an MNE. An MNE with headquarters in peripheral country 4 and a subsidiary in country 2, with connections both to local and foreign universities, is a type 3 interaction, equivalent to an MNE with headquarters in country 1 at the centre and a subsidiary in country 3. Over time, what changes is the appearance of MNEs based in peripheral countries (UNCTAD 2006).

Second, this taxonomy does not include a type of relationship that includes informal contacts – Ernst's "informal social networks." According to the literature on interactions, informal contacts constitute one very important source of information even in developed countries (Cohen et al. 2002). Students sent abroad, brain drain, and brain gain are part of

the dynamics of internationalization of science that could be described in Figure 8.1 as direct contacts between universities from the four countries. This taxonomy was designed to describe global interactions between firms and universities; therefore, these movements within the scientific networks are not defined as a separate type. However, these movements within scientific networks are very important to the constitution of global interactions. In fact, they are an essential precondition.

All of the changes in globalization of interactions can be evaluated using this taxonomy, which is necessarily static. However, it can be elaborated to deal with a very dynamic environment. MNEs from developing countries are a new phenomenon. Therefore, if Figure 8.1 were drawn to represent dynamics in the early 1950s, the arrow connecting an MNE headquarters in country 4 and its subsidiary in country 2 would not exist. Furthermore, the broken line between the centre and the periphery, between countries 2 and 4, opens up the possibility for catching-up processes and for overcoming underdevelopment.

Another important dynamic feature is pointed to by the literature on networks. That is, "networks and innovation constitute a virtuous cycle" (Powell and Grodal 2005, p. 67). The knowledge exchanges and trust built during collaborative work, and the achievements of the network, mean that over time networks may become less hierarchical. These network improvements over time must be incorporated into the taxonomy. Finally, the taxonomy includes the empirical regularities unveiled by the literature on interactions (Cohen et al. 2002) and transnationals (Dunning 1993) regarding sectoral specifics.

The integration between the literature on GINs and on interactions between firms and universities, and the synthesis of a framework to characterize global interactions between firms and universities, has an important theoretical consequence: the subject of the interdependence between national systems of innovation is clearly on the agenda.

A METHODOLOGY FOR UNVEILING GINs

The new methodology developed to map these connections is an extension and an improvement of an earlier methodology to map interactions between local firms and universities (Ribeiro et al. 2010). In that study, we developed a methodology and software for collecting information on patents granted by the United States Patent and Trademark Office (USPTO). The first step in the present work was to use this software to search and download a set of information for all patents granted in the year 2009: (1) USPTO patent number; (2) first inventor's country (if

from the US, the first inventor's state); (3) assignee's name; (4) assignee's country (if from the US, the assignee's state); (5) application date; (6) issue date; (7) USPTO patent number of each cited US patent; (8) other references cited by the patent (these are the non-patent references); and (9) US classification code (class and subclass).

For our new analysis of all types of interaction, the next step was to focus on the non-patent references (e.g., scientific articles and manuals). Thereafter, we split the text of each reference into four parts: authors, title, journal, and other information. Using specially created software, the data on title and journal were used to search and identify the article on the Institute for Scientific Information (ISI) site. For this chapter, the search was limited to the 1000 most cited journals. After the article was located, the software collected the following information: (1) title; (2) authors' institutional address; (3) source; (4) publication date; (5) publisher; (6) web of science category; (7) subject category; (8) ISSN; and (9) DOI.[2]

Using these datasets, we prepared two lists of firms and institutions: one with all patenting firms in 2009; and one with all institutions that authored papers cited in 2009. The institutional authors were classified as either MNE headquarters, MNE subsidiary, local firm, or research institution. To classify the firms, we used available lists such as Global Fortune 500, United Nations Conference on Trade and Development (UNCTAD), and institutional websites.

We were able to connect a patenting firm, located in a specific country, with the research institute, university, or even the firm that had authored the paper cited in the patent application. These links are the key relationships we investigated. Therefore, our database and methodology are tools to empirically verify the existing scale and nature of global interactions between firms and research institutions.

The literature on interactions between firms and universities (Klevorick et al. 1995; Cohen et al. 2002) indicates the multifarious channels of knowledge flow that run both ways: publications; informal exchange; consultancy; hiring of recent graduates; conferences; and cooperative research. In the case of the US, publications are ranked in first place as the main "channel of interaction" (Cohen et al. 2002, p. 15). In the case of a peripheral country such as Brazil, publications and reports are also ranked in first place (Fernandes et al. 2010, p. 491). This methodology therefore captures only one – but a very significant – feature of global interactions between firms and universities. It is based on interactions represented by codified knowledge, as documented by patents, and the formal channels between firms and universities, as represented by the scientific

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[2] ISSN = International Standard Serial Number; DOI = Digital Object Identifier.

Table 8.1   Country distribution of patents and cited papers (2009)

	Country	Patents		Country	Institutional authors
1	US	74068	1	US	17671
2	Japan	35312	2	Japan	879
3	Germany	8709	3	Germany	652
4	South Korea	8577	4	Great Britain	617
5	Taiwan	5804	5	Canada	418
6	Canada	3181	6	Switzerland	269
7	France	3052	7	France	192
8	Great Britain	3018	8	Sweden	186
9	China	1633	9	Netherlands	153
10	Ireland	1303	10	Ireland	131
11	Netherlands	1262	11	South Korea	126
12	Italy	1221	12	Italy	119
13	Switzerland	1169	13	Australia	105
14	Australia	1123	14	Spain	87
15	Sweden	979	15	Belgium	80
16	Finland	829	16	Taiwan	79
17	India	657	17	New Zealand	76
18	Belgium	575	18	Denmark	74
19	Austria	467	19	China	45
20	Singapore	420	20	Finland	41
21	Denmark	372	21	Russian Federation	32
22	Spain	293	22	Austria	29
23	Norway	248	23	Turkey	27
24	Ireland	169	24	India	27
25	Russian Federation	160	25	Hong Kong S.A.R.	27
26	Hong Kong S.A.R.	157	26	Norway	24
27	Malaysia	154	27	Singapore	15
28	New Zealand	112	28	Argentina	13
29	Brazil	85	29	Latvia	12
30	South Africa	74	30	South Africa	12
31	Mexico	48	31	Ireland	10
32	Czech Republic	39	32	Portugal	8
33	Hungary	39	33	Iran	7
34	Luxembourg	36	34	Slovenia	6

publications cited by those patents. Those channels are interpreted as proxies of broader relationships, but they are sufficient to provide strong empirical evidence of global links.

Descriptive statistics provide a general picture of the scope of our preliminary results. Table 8.1 shows the country distribution of patents and

cited papers. The leading position of the US, Japan, and some European
countries is immediately evident. Looking at the total number of patents,
the position of catch-up countries like South Korea and Taiwan (in 4th
and 5th positions) and China (in 9th position) can be highlighted. India
lies in the 17th position, Brazil in 29th, and South Africa in 30th.

In terms of the total number of cited papers, the leading positions of
the US, Japan, and Germany are preserved, but Great Britain (in the 4th
position) overtakes South Korea and Taiwan, whereas India and Brazil
fall to the 24th and 44th positions (the latter is not shown in Table 8.1),
respectively.

Table 8.2 shows both the leading patenting firms, and the leading patent-
ing firms with non-patent references (scientific paper citations are one of
the non-patent references). Firms related to the present technological para-
digm are ranked in the leading position. In our earlier work, the main peak
in our matrices of science and technology (S&T) interactions was in the
matrix cell "information technology" × "electronic engineering" (Ribeiro
et al. 2010, p. 59). This is also reflected here, as the leading patenting firms
are IBM, Microsoft, Samsung, Panasonic, and Siemens. The leading role
of IBM in both columns of Table 8.2 is evident. Only firms from the US,
Japan, South Korea, and Germany are in the first 20 positions.

Table 8.3 presents the other side of these global interactions: the leading
25 institutions that authored the papers cited in these patents. These were
all US based. There were only four non-US universities or institutions
within the 52 leading institutions, and these institutions were located in
England, Israel, and Japan.

Table 8.3 reflects that two US firms are leading authors of cited papers
(Genetech and IBM). Genetech, the pioneering firm in the biotechnology
sector, is in the 14th position – and is not in the current leading techno-
logical paradigm. The presence of IBM as the 25th leading author of cited
papers is also noteworthy; IBM is the only firm that is present in both
Tables 8.2 and 8.3.

These preliminary descriptive statistics present the general context from
which our detailed analysis begins: the identification of firms, institutions,
and their locations. This database provides us with data to track the flows
and "streams of innovation" between firms, institutions and locations.

IBM AS A CASE STUDY

IBM is an excellent starting point for an illustrative description of our
database and methodology. As the leading patent firm (Table 8.2), and
as one of the firms that has papers cited in patents (Table 8.3), this global

Table 8.2 Ranking of patenting firms, and ranking of patenting firms with patents citing non-patent references (NPR) (2009)

Patenting firms	Country	Patents	Patenting firms citing NPRs	Country	Patents
International Business Machines Corporation	US	3947	International Business Machines Corporation	US	2128
Samsung Electronics Co. Ltd.	KR	3015	Microsoft Corporation	US	2100
Microsoft Corporation	US	2612	Samsung Electronics Co. Ltd.	KR	1321
Canon Kabushiki Kaisha	Japan	2094	Panasonic Corporation	Japan	926
Panasonic Corporation	Japan	1675	Kabushiki Kaisha Toshiba	Japan	837
Kabushiki Kaisha Toshiba	Japan	1574	Canon Kabushiki Kaisha	Japan	826
Sony Corporation	Japan	1504	Intel Corporation	US	806
Intel Corporation	US	1308	Sony Corporation	Japan	638
Seiko Epson Corporation	Japan	1230	Fujitsu Limited	Japan	628
Hewlett-Packard Development Company L.P.	US	1105	Hewlett-Packard Development Company L.P.	US	589
Fujitsu Limited	Japan	1095	Cisco Technology Inc.	US	558
LG Electronics Inc.	KR	1026	Micron Technology Inc.	US	547
Hitachi Ltd.	Japan	983	LG Electronics Inc.	KR	494
Micron Technology Inc.	US	880	Hitachi Ltd.	Japan	464
General Electric Company	US	835	Semiconductor Energy Laboratory Co. Ltd.	Japan	418
Cisco Technology Inc.	US	780	Seiko Epson Corporation	Japan	404
Ricoh Company Ltd.	Japan	726	Ricoh Company Ltd.	Japan	392

Table 8.3   *Ranking of institutions that authored papers cited in patents*
              (2009)

	Institution	Type	Country	Cited papers
1	Harvard Univ	RI	US	1569
2	MIT	RI	US	711
3	Stanford Univ	RI	US	683
4	Univ Texas	RI	US	613
5	Univ Calif San Francisco	RI	US	436
6	NCI	RI	US	434
7	Univ Washington	RI	US	387
8	Univ Calif Berkeley	RI	US	385
9	Univ Calif San Diego	RI	US	354
10	Univ Penn	RI	US	340
11	Johns Hopkins Univ	RI	US	331
12	Washington Univ	RI	US	320
13	Cornell Univ	RI	US	313
14	Genetech Inc	MNE–S	US	309
15	Yale Univ	RI	US	294
	(data not presented to show non-US sources)			
25	IBM Corp	MNE–H	US	205
	(data not presented to show non-US sources)			
28	MRC	RI	England	194
	(data not presented to show non-US sources)			
31	Univ Toronto	RI	Canada	184
	(data not presented to show non-US sources)			
35	Hebrew Univ Jerusalem	RI	Israel	170
	(data not presented to show non-US sources)			
44	Univ Tokyo	RI	Japan	146
	(data not presented to show non-US sources)			
52	Univ Cambridge	RI	England	126

Note: Institutional authors: RI = Research Institutions; MNE–H = Multinational
Enterprise – Headquarters; MNE–S = Multinational Enterprise – Subsidiary.

firm may provide an excellent case to see how our data can describe flows
between firms and research institutions. Furthermore, IBM was a firm
highlighted in a pioneering paper by Narin et al. (1997, pp. 329–330),
which described how IBM used scientific information from domestic and
foreign sources.

   Table 8.4 summarizes information flows from IBM headquarters and
its subsidiaries, and their use of scientific information provided by papers
from different countries. The first column shows the location of the

Table 8.4   Information flows and use of scientific information by IBM and its subsidiaries (2009)

Patent country	Cited paper's institution	Type	Cited paper country	Cited papers
US	MIT	RI	US	13
US	IBM Microelectric	MNE–H	US	10
US	IBM Corp	MNE–H	US	8
US	Princeton Univ	RI	US	6
US	Auburn Univ	RI	US	5
US	Polytechnic Milan	RI	Italy	5
US	Georgia Inst Tech	RI	US	4
US	Siemens AG	MNE–H	Germany	4
US	Cornell Univ	RI	US	3
US	Delft Univ Technology	RI	Netherlands	3
US	Simon Fraser Univ	RI	Canada	3
US	ST Microelectronics	LF	Italy	3
US	Univ Cambridge	RI	England	3
US	Indian Inst Technol	RI	India	2
US	Inesc	LF	Portugal	2
US	Max Planck Inst	RI	Germany	2
US	Royal Inst Technol	RI	Sweden	2
US	Swiss Fed Inst Technol	RI	Switzerland	2
US	Univ Seoul	RI	S. Korea	2
US	Weizmann Inst Sci	RI	Israel	2
US	Acad Sci Czech Rep	RI	Czech Rep.	1
US	Associe Cnrs	LF	France	1
US	Chinese Acad Sci	RI	China	1
US	Imec	LF	Belgium	1
US	Inst Engn Sist & Comp	RI	Portugal	1
US	Natl Nano Device Lab	RI	Taiwan	1
US	Nilprd	LF	Romania	1
(data not presented to show non-US sources)				
Switzerland	ETH Honggerberg	RI	Switzerland	1
Switzerland	IBM Res GmbH	MNE–S	Switzerland	1
Switzerland	Miromico AG	LF	Switzerland	1
Switzerland	Paul Scherrer Inst	RI	Switzerland	1
Switzerland	Washington Univ	RI	US	1
Japan	Queens Univ Belfast	RI	Ireland	1
New Zealand	IBM Corp	MNE–H	US	1
New Zealand	Sumitomo Elect Ind Ltd	LF	Japan	1

Note: Institutional authors: RI = Research Institutions; MNE–H = Multinational Enterprise – Headquarters; MNE–S = Multinational Enterprise – Subsidiary; and LF = Local Firm.

specific IBM unit: there are patents from the US headquarters and from subsidiaries located in three foreign countries (Japan, Switzerland, and New Zealand). The second column shows the institution that authored the paper cited in these patents; the third column the nature of that institution (a research institute, a local firm, or the headquarters or subsidiary of an MNE); the fourth column the country in which the institution is located; and the fifth column the number of citations received by papers from that specific institution.

Table 8.4 demonstrates the international flows that link US branches of IBM that cite papers from developed foreign countries such as Switzerland, Japan, Germany, France, England, Netherlands, Israel, Belgium, and Portugal. Additional data (not shown) demonstrate that these links extend to catch-up countries such as South Korea and Taiwan, developing countries such as India and China, and transition countries such as Czech Republic and Romania. An IBM subsidiary located in Switzerland cited papers from local institutions and from institutions in the US. The Japanese subsidiary cited an Irish research institution, and the subsidiary from New Zealand cited research institutions from the US and Japan.

In addition to universities, firms were also cited. IBM patents cited papers authored by firms like IBM itself, US firms like Eaton Corp. and Infineon Technologies Corp., and Japanese firms like Sumitomo Electric Industries Ltd, Sony Corp., and Toshiba Corp. It is clear that IBM has flows that connect it with research institutes, MNE headquarters and subsidiaries, and with local firms.

Table 8.4 provides a picture of the scope of the links organized by IBM globally. It provides a strong indication of the capability of this MNE to absorb knowledge generated all over the world, a tremendous flexibility probably not available to smaller global corporations. Table 8.4 also illustrates that our methodology can offer the kind of picture we are looking for – the ability to identify connections between firms and universities, and between firms and firms that cross national frontiers. Global interactions can also be captured by this methodology.

STREAMS OF INNOVATION

The example provided by the IBM case leads us to proceed to the next step of our inquiry: a look at the country level. A country (e.g., the US) or a region (e.g., Europe) may be seen as an aggregation of diverse firms and other institutions, as well as the knowledge flows between these firms and institutions, both within and beyond national borders. To illustrate this level of analysis, we first present the case of the US (Table 8.5). The data

Table 8.5 *Institutional authors of papers cited by patents from US,*
disaggregated by their geographic location and by types of
institutional authors (2009)

Country of cited paper	Institution frequency	RI frequency	MNE–H frequency	MNE–S frequency	LF frequency
US	22169	17814	967	459	2929
Japan	2076	1579	101	84	312
Germany	1361	1162	18	57	124
England	1265	1080	12	52	121
France	1107	838	40	22	207
Canada	985	909	0	7	69
Italy	697	549	5	16	127
Switzerland	579	397	10	35	137
Netherlands	532	470	8	6	48
Israel	432	376	0	6	50
Sweden	427	382	0	12	33
Australia	311	259	0	0	52
Belgium	294	254	0	18	22
South Korea	268	247	1	5	15
Spain	264	196	0	2	66
Taiwan	245	237	0	0	8
China	236	233	0	2	1
Austria	218	208	0	2	8
Finland	199	178	0	2	19
Denmark	169	137	4	2	26
Scotland	119	104	0	0	15
Russia	102	97	0	0	5
India	97	92	0	0	5
Norway	75	66	0	0	9
Poland	67	65	0	0	2
Brazil	50	48	0	0	2
Ireland	47	46	0	0	1
Singapore	47	45	0	0	2
TOTAL	34885	28471	1166	796	4452

Note: Institutional authors: RI = Research Institutions; MNE–H = Multinational
Enterprise – Headquarters; MNE–S = Multinational Enterprise – Subsidiary; and
LF = Local Firm.

for the US are disaggregated by type of institutional author of the cited
papers and by their geographic location. Next, we compare the US data,
now aggregated, with aggregated data from five countries and one region
(Table 8.6). These data were the basis for a map that graphically expresses
global innovation networks.

Table 8.6   *Institutional authors of papers cited by patents from selected*
countries and from Europe, aggregated by number of countries
cited, by types of institutional authors, and by their domestic or
foreign location (2009)

Home country	Countries cited	Institution authors	RI	MNE–H	MNE–S	LF	Domestic location	Foreign location
US	73	34885	28471	1166	796	4452	64%	36%
Europe	54	3823	3108	105	79	531	39%	61%
Japan	40	1634	1261	74	44	255	26%	74%
China	16	78	63	1	4	10	6%	94%
India	10	57	51	0	1	5	2%	98%
South Africa	18	45	43	0	1	1	0%	100%
Brazil	6	10	6	0	0	4	0%	100%

Note: Institutional authors: RI = Research Institutions; MNE–H = Multinational Enterprise – Headquarters; MNE–S = Multinational Enterprise – Subsidiary; and LF = Local Firm.

Table 8.5 describes data for the US. Patenting firms located in the US cited papers authored in 73 different countries (Table 8.6). This is a first indication of how widespread these networks are that originate in the US. Table 8.5 shows that patents from US-based firms cited a total of 34 885 institutional authors from papers produced by research institutes and firms. US-based patenting firms cited mostly US-based institutional authors (22 169 institutional authors – 64% of the 34 885 total, Table 8.5). The 22 169 domestic institutional authors were from 2317 different institutions, mostly from research institutions – 17 814 institutional authors were from 1141 different research institutions. The importance of other sources may be grasped from the number of citations of papers authored by firms – 2929 institutional authors were in local firms (non-MNE firms), 967 institutional authors were in MNE headquarters, and 459 institutional authors were in MNE subsidiaries (those institutional authors were located in, respectively, 943 local firms, 178 MNE headquarters, and 55 MNE subsidiaries). More institutional authors were in the MNE headquarters than in the subsidiaries. The second source of citations was European countries, with Japan in third place. For these two locations, many types of institutions were cited (research institutions, local firms, MNE headquarters, and MNE subsidiaries).

   Table 8.5 organized the relevant data for the evaluation of international networks based on patenting firms. The US case was useful because

it illustrated a broad global network that spanned all continents and included all different information sources. A comparison of other countries and regions with the US case is shown in Table 8.6, which summarizes and aggregates the indicators of the flows by country and region. Table 8.6 shows that the US had the largest global base of international networks – 73 countries were the sources of the papers cited. The US was followed by Europe as a region (citing 54 countries) and Japan (citing 40 countries). Countries representing the South (China, India, South Africa, and Brazil) were cited less often, and correspondingly fewer countries were sources of the citations in their patents. The North–South divide in the size of flows is clear, as measured by the total of institutional citations – all four of these countries have fewer than 100 institutional citations.

Only in the US did domestic sources account for more than half (64%) of the total institutional citations (Table 8.6). Domestic sources accounted for 39% of institutional citations in Europe and 26% in Japan. The pattern was very different in the four countries from the South (e.g., only 6% of citations were from domestic sources in China). This may be an indication of the importance of foreign sources for immature NSIs. Public policies to strengthen the size and quality of local S&T infrastructure are required if NSIs are to improve. Figure 8.2 illustrates these international flows.

Figure 8.2 summarizes data presented in Table 8.5 for the US,[3] and aggregates similar information from Europe, Japan, China, India, South Africa, and Brazil. As an example of how the maps are prepared, the maps for the US and Brazil are included. These two maps illustrate the most internationally connected and the least internationally connected countries in our sample.

Figure 8.2 contributes to our investigation in two ways. First, it shows how the different types of interactions in our taxonomy compose the global picture. Second, it expresses graphically the persistence of strong hierarchies in the global scientific and technological scenario – a renewed warning of the international cooperative measures required to soften the prevailing North–South divide.

CONCLUSION

The theoretical framework presented in this chapter helps to analyse the role of universities in GINs, and the ways in which emerging countries

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[3] The size of the flows for the US is in line with our earlier findings (Ribeiro et al. 2010). US patents have a higher propensity to cite papers and reports. Therefore, there is a gap between total US institutional citations and the rest of the world, even Europe and Japan.
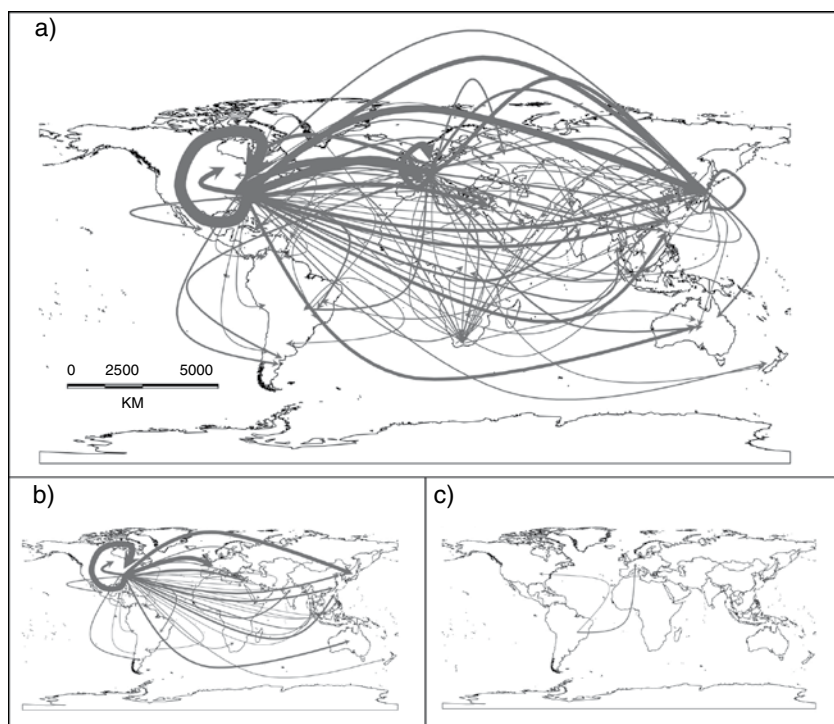
Figure 8.2   *(A) Global flows of interactions; (B) flows of interactions for
                the US; and (C) flows of interactions for Brazil*

are inserted into global hierarchies. The goal is to catch up – to improve a
country's insertion into global hierarchies through GINs. The proposition
that both MNEs and the processes of NSI formation shape GINs has one
important implication: the nature of NSIs shapes the national role in exist-
ing GINs. Therefore, immature NSIs will have immature (or incomplete)
GINs – the limits of the NSIs will be reflected in the sectors and the nature
of these GINs.

   The flows described in this chapter hint at the widespread nature of
these interactions – as reflected through our analysis of the papers cited
in patents. The flows describe a general picture of increasing interdepend-
ence between countries. They confirmed findings from Narin et al. (1997)
that showed how a global firm like IBM benefited from global research.

Our data also showed how widespread these global networks are among leading global firms.

This leads to one simple conclusion – investment in the formation of NSIs is crucial as a guarantee of a less subordinate role in an emerging global system of innovation. This process of formation and improvement, with growing global connections and interactions, is a precondition for a more equal world – a world in which overcoming this hierarchical divide is a real global goal.

Postscript: Researching university–industry links: where do we go from here?

David O'Brien and Isabel Bortagaray

This postscript analyses the experiences of a research programme seeking to conceptualize and quantify university–industry links (UILs) in Asian, Latin American, and African countries. Although this topic has generated a considerable body of research in high-income countries, little empirically grounded research has been conducted elsewhere. Our aim is to learn from this pioneering research programme to inform future UIL research directions in low- and middle-income countries.

The Changing Role of Universities in the South (Changing Universities) research programme supported studies that examined: (1) how and why universities in low- and middle-income countries were transforming to meet their research, teaching, and outreach missions; (2) what changes or roles would advance their development potential; and (3) how should universities link their entrepreneurial and research functions? The last question generated considerable interest and more than 30 researchers were funded by the International Development Research Centre (IDRC) and a number of other agencies to examine UILs across Asia, Africa, and Latin America.[1]

Before the research began, the research teams had independently identified a common challenge in their funding proposals. First, the requisite data needed to quantify UILs (e.g., surveys of industry and research organizations) were not available in their countries of study, except in a few instances. Second, a number of researchers questioned the utility of replicating survey instruments developed in "mature" innovation systems and applying them in low- and middle-income country settings. From the outset, the research teams needed to design suitable survey instruments and collect data to analyse the determinants and consequences of

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knowledge flows between universities, and in some cases other kinds of public research organizations (PROs),[2] and the private sector.[3]

The research teams implemented studies in twelve countries, and the results have been published widely.[4] Given the dearth of empirical research on this subject, the body of research generated from the programme represents a quantifiable step forward in understanding UILs in developing countries.

By drawing on the reflections of the researchers, this postscript has three aims:

(1) review the conceptual developments for identifying the channels and the benefits of knowledge flows between PROs and industry;
(2) discuss the empirical methods used and challenges faced; and
(3) identify future research directions based on the experiences of researchers.

DESCRIPTION OF THE CHANGING ROLE OF UNIVERSITIES IN THE SOUTH

The Changing Universities programme was launched in 2005, and identified research on UILs as a priority. The programme set out to understand how the privatization of knowledge was influencing public universities, and how universities were interacting with organizations such as governments, industry, and civil society organizations to advance common goals.

Despite the increasing interconnectedness among universities and their common missions, universities remain very different. One key difference is their embeddedness in their community and national environment. Arguably, the emphasis on research and education is relatively common, whereas interest in the third, outreach mission, varies considerably across countries. In Latin America, for example, university outreach has a long-standing tradition. In the early 20th century, universities played an active role in shaping political and cultural developments. Student movements expanded the role of the university in cultural, economic, and political

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[2] Some research projects analysed both universities and PROs, but that distinction is not made here.

[3] See Kruss et al. (2009, pp. 1–2) for a retrospective discussion of the research objectives and challenges of the research programme.

[4] In addition to the chapters in this book, a select list of previous publications includes: Albuquerque et al. (2008); Eom and Lee (2009); Intarakumnerd and Schiller (2009); Joseph and Abraham (2009); Rapini et al. (2009); Adeoti et al. (2010); Arza and Vázquez (2010); Dutrénit and Arza (2010); Dutrénit et al. (2010b); Fernandes et al. (2010); Orozco and Ruiz (2010); Suzigan and Albuquerque (2011); and Kruss et al. (2012).

transformations designed to address the needs of the underprivileged. This trajectory was quite different in Brazil, where universities emerged, strictly speaking, after the 1920s. Despite some significant contributions to Brazil's technological development (Suzigan and Albuquerque 2011), the government belatedly acknowledged the third mission of public universities in the 1980s (Arocena and Sutz 2005b).

As recognition has increased that research and knowledge are crucial for development, the relationship between universities and society has been transformed. Lam (2012) and others have noted the entrepreneurial shift in the third mission of universities toward "knowledge capitalization." This paradigm stresses the role of knowledge for economic activity (Clark 1998; Etzkowitz 2003). Although this orientation enjoys considerable government support, some observers argue that the third mission should go beyond industrial application and emphasize its contribution to building learning societies. For example, the notion of a "developmental university" proposed by Arocena and Sutz (2005a) expands the debate by drawing attention to the multiple and valued pathways universities contribute to social, cultural, and economic development.

Current debate on the appropriate or desired role of universities in linking with industry, agriculture, service sector, and health is widespread, transcending countries with different political and economic systems (Göransson and Brundenius 2011). However, empirical research on UILs, and the costs and benefits of collaboration with industry, is geographically concentrated in high-income countries. The paucity of empirical data in low- and middle-income countries means that efforts to promote innovation through education or industrial policy are guided by intuition rather than informed by evidence.

Emerging from the Changing Universities research programme is a new body of research focusing on: (1) the determinants of university interactions; (2) the frequency and intensity of these interactions; and (3) the results of these interactions. The studies make an important empirical contribution to understanding the dynamics of UILs in low- and middle-income countries.

METHOD

Two years after the conclusion of the research programme, we contacted the lead researchers who were supported in whole or in part by IDRC funding, and had published an article or a book. One third of the principal researchers responded to an email requesting written responses to the following questions:

(1)   What were the research questions or hypotheses tested?
(2)   What was the research design? What empirical methods were used?
(3)   In collecting data, did you adapt existing or develop new survey instruments? If you adapted or replicated survey instruments used in a high-income country, what was or was not transferable?
(4)   What were the challenges of conducting research (e.g., data availability or appropriate indicators)?
(5)   If you could repeat the research, what would you do differently? Is there a need to develop new research tools to strengthen research on UILs? What would these look like; what would they do that existing tools prevent you from doing or understanding?
(6)   How do UILs impact university missions? Describe the challenges, incentives, organizational processes, or obstacles.
(7)   What is needed to advance research on UILs?

In addition to feedback on these questions, we consulted the unpublished technical reports, published articles, and books. We received additional feedback from researchers involved in the Changing Universities programme at a 2011 International Workshop on University–Firm Interactions in Sao Paulo, organized by the book editors.

MAIN FINDINGS

The Changing Universities programme funded regional and national studies that focused on UILs. There were three multi-country comparative research studies in Latin America, sub-Saharan Africa, and Asia, and four country studies. In an attempt to promote comparability of findings across countries, a start-up workshop brought together the lead researchers to explore commonalities and opportunities for collaboration. The workshop resulted in an overall conceptual approach, a questionnaire, and an intent to compare findings.

The main research questions that the teams explored can be grouped under three headings:

(1)   Determinants of UIL:
    (a)   What are the motivations and incentives driving UILs from the perspective of both firms and researchers?
    (b)   What structural conditions (e.g., firm size, location, and capabilities of universities) influence when, where, and who interacts?
    (c)   How do the meso- and macro-level institutional contexts influence UIL?

(2) Modes of Interaction:
    (a) What channels are used to create links?
    (b) What is the extent of UILs?
    (c) How do the characteristics of links vary by location, firm characteristics, and academic discipline?
    (d) What is the relative importance of universities compared with other information channels available to industry?

(3) Outcomes:
    (a) What are the benefits and risks of UILs?
    (b) Do researchers and industry representatives share similar perspectives on the benefits?

These questions were not uniformly investigated by all research teams. However, there was a common interest in examining the claim that innovation systems in low- and middle-income countries were fragmented, and that the links connecting the generators and users of research were weak. Teams sought to affirm or reject the commonly held assertion that PROs and industry do not interact to the degree required to generate much value from their interactions.

Research Designs and Empirical Methods

The research competition imposed certain limitations on research designs. The time and funds available were perhaps the most significant constraints researchers had to work within when proposing their scope of research. Most projects had 24 months to design their studies and collect and analyse the data. Some teams found this time period too short to conduct original empirical research. One obvious consequence was the inability to collect time-series data. Only in a couple of studies did researchers identify existing data sources that enabled them to compare changes over time.

Funding was the second programme constraint on research design. On average, each country study had a research budget of CAD 45,000 (CAD1 = USD 0.91). In some countries this was adequate. But as research progressed in other countries, collecting survey data from firms and researchers proved to be more costly and time consuming than anticipated. And yet, the sample sizes summarized by Pinho and Fernandes (Chapter 5, this book) suggest that teams were largely successful in reaching their desired data-collection targets.

Data collection focused on surveys of firms and researchers. In addition, some teams developed complementary case studies that outlined the historical, institutional, and behavioural context needed to interpret quantitative findings, and comment on evolutionary dynamics (Kruss et al.

Table P.1   Existing empirical data cited in the country studies

	Firm innovation or R&D surveys	Citation of UIL case studies	University surveys of UILs
Thailand	Yes	Yes	No
Malaysia	No	Yes	No
India	No	Yes	No
China	No	Yes	No
Korea	Yes	Yes	No
Nigeria	No	Some	No
Uganda	No	Some	No
South Africa	Yes	Yes	No
Mexico	Yes	Yes	No
Argentina	Yes	Yes	No
Brazil	Yes	Yes	No

Note: Some but not all papers distinguished between innovation and firm R&D surveys. If either one of these existed, we entered Yes.

Sources: Seoul Journal of Economics (2009); Kruss et al. (2009); Arza (2010).

2009, Annex II). In a few cases, the mixed-methods approach helped compensate for difficulties in collecting survey data. In Uganda and Nigeria, for example, where firms were reluctant to respond to a survey request, the research team shifted their attention to case studies.

Table P.1 characterizes the data the teams identified in each country. Except for a few countries, there were some existing data on firm research and development (R&D) and case studies on successful UILs.

The second column indicates the existence of firm surveys. As Schiller and Lee (Chapter 2, this book) note, firm-innovation surveys tend to measure a firm's formal links but, in their view, provide a limited view of the range of links a firm may use. Although most teams questioned the suitability of firm R&D studies for examining UILs, they were available in most countries.

The third column identifies case studies. Most country studies drew on published case studies to report relevant findings. However, as Joseph and Abraham (2009, p. 469) describe for India, the existence of case studies is not a satisfactory starting point for understanding UILs:

> . . . with the possible exception of a few studies, university industry interaction in India remains an unexplored area. The existing studies have their limited relevance for broad based policy making as they are mostly case studies of [a] leading S&T institute or laboratory, and of a specific industry, or of selected cities.

The fourth column shows that no team noted existing UIL surveys that examined the perspectives of university-based researchers on their links with industry. This was the clearest conceptual and empirical gap in the literature.

Unable to piece existing data together in a meaningful way, the research teams designed new surveys for firms and for researchers working in PROs. Where teams surveyed the attitudes and activities of researchers (e.g., who they collaborated with, why, on what terms, and the perceived benefits/costs of collaboration), it represents a significant step forward. The links are relational and benefit from being studied from a supply (researcher) and demand (firm) perspective. The combined data from the two surveys generated a two-way view of university–industry relationships. By investigating the perspectives of both, the teams were able to generate a fuller picture than was available previously.

Adapting Survey Instruments to Meet Domestic Realities

In both the research proposals and the final reports to IDRC, research teams concurred that existing survey instruments deployed in the US and Europe were relevant but not wholly appropriate. As Keun Lee explained: ". . . the Yale Survey (Klevorick et al. 1995) and the Carnegie Mellon Survey (Cohen et al. 2002) are the starting points for designing the national survey questionnaires . . . Modification of the Yale and Carnegie Mellon questionnaires is necessary given the present stage of development of the UILs in developing countries."[5] Among the modifications the teams made were: reducing the number of questions; adding more relevant academic disciplines and sectors; and introducing new channels of interaction.

These modifications to the US surveys demonstrated an interest in making future comparisons with US findings, but the questions were tailored to resonate with respondents working in quite different economic contexts. There would be respondents citing universities transferring knowledge through formal channels to technologically advanced sectors, but there would also be small enterprises working informally with researchers. These differences revealed themselves in the US results (Cohen et al. 2002, p. 17), but the differences were likely to be more pronounced in the countries studied. Conscious of different economic environments, the teams expanded the range of formal and informal channels that firms and researchers might use.

The authors of the IDRC studies set out to explore the channels of

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[5] This quote is from Keun Lee's proposal to the Changing Universities competition (unpublished).

information flow in greater detail, and this resulted in two unique contributions. First, the authors introduced a wider range of channels through which information might flow. Second, the studies asked both firms and university-based researchers what channels they used.

Turning first to the expanded range of channels, the authors of the Thailand study remarked:

> The analysis of UILs in developed countries is often limited to formal research collaboration via patent licensing or spin-off companies. It is necessary to broaden this view and to cover more informal modes, e.g., consulting and technical services, and UIL in teaching. These modes are especially relevant in developing countries because they fit better with the absorptive capacity of firms and academic capabilities of universities in most cases. (Intarakumnerd and Schiller 2009, p. 585)

Adding to the categories used by Cohen et al. (2002), numerous teams introduced additional channels. Table P.2 identifies the channels used by the Cohen study, and additional channels introduced in the various country studies. In the right column, a characterization of the information channel is suggested, although the distinctions are best thought of as a continuum.

As discussed in Chapters 2 and 5 of this book, identifying the channels used in different contexts contributes to theory building and policy. As suggested in Chapter 2, the rationale for modifying US survey instruments is based on a "stages of economic development" argument, which

Table P.2   UIL channels along a formal–informal interaction spectrum

UIL channels (Cohen et al. 2002)	Additional channels (IDRC studies)	Continuum of UIL characteristics
Patenting and licensing	Joint laboratories	Top-down Formal Proprietary ▼
Contract research	Incubators	
Consulting	Sale of products	
Joint ventures	Spin-offs	
Public meetings and conferences	Participation in networks and R&D consortia that involve universities	
Publications and reports	Technical services	▲ Public Informal Bottom-up
Hiring graduates	Training of industry staff	
Informal interaction	Staff mobility	
	Internships	

is understandable. However, when survey results were analysed, country preferences for UIL channels seemed to be better explained by socio-political factors than by economic structure. Interestingly, the propensity to use informal channels in the US was similar to many Latin American cases, but differed significantly from China, where formal channels (e.g., contract research) were most prevalent.

These differences are important for policy because strategies for enhancing UILs need to understand and build on the collaborative preferences of those likely to be involved. For example, encouraging open-science platforms would likely be far more effective in Latin America, given the preference there for informal interactions between firms and researchers, than it would be in China, where there is a preference for contractual links.

The second contribution teams made was coupling firm and researcher perspectives on information flows. As Table P.1 indicated, researchers were able to draw on firm R&D studies and national innovation surveys, but there were no similar data on how researchers viewed their links with industry. Interactions between industry and universities imply that there is demand from industry and a supply from universities. The supply response is particularly important for a number of channels to work well. If university-based researchers are not interested in working with industry, the number of channels available will decrease.

Having collected data from researchers and firms, numerous studies were able to comment on the perceived satisfaction of firms and researchers. The findings are generally very encouraging. When surveyed, firms and researchers were inclined to work with each other, and when they did, satisfaction rates were high (Chapter 5, this book). These results question the widely held view that academic researchers in low- and middle-income countries are disinterested in collaborating with industry.

Main Research Challenges

Understanding the challenges faced during the research process can provide useful lessons to guide funding agencies and researchers. As could be anticipated, many teams encountered challenges collecting representative data from firms and researchers.

This challenge is not unique to this project. All empirical research that relies on collecting reliable data from a desired population has its challenges. Respondents had different experiences designing samples and collecting data. Representative samples are required to make statistically meaningful statements, such as whether small or large firms, or whether agricultural or automotive firms, benefit more from university

links. This can be time consuming and costly data to collect. As was the case in several countries, the study population was poorly defined and not easily quantified. Accessible and informative business registries were often lacking, which made it difficult to construct random representative samples. This challenge, coupled with the low incidence of UIL in some countries, resulted in the pragmatic suggestion by some researchers to emphasize case-study research over quantitative surveys.

Several country teams faced low response rates that required additional effort to follow up with respondents. In a few cases, this additional effort was still unable to secure the level of cooperation desired by the teams. Perhaps anticipating such challenges, the Malaysian research team contracted out its data collection to a public opinion firm, which reportedly worked well (Rasiah and Govindaraju 2009).

For the data that were collected, several teams expressed concerns with reliability. In the Uganda study, Nabudere (2008a) identified three challenges that were shared to varying degrees by others. In his sampling strategy, Nabudere targeted firms that used traditional knowledge of native plants in their products. He suspected that firms in this sector (e.g., medicinal products and food stuffs) were weary of how survey findings would be used, and did not respond accurately. More generally, firms experienced difficulties understanding some of the concepts and the wording of the surveys, which was evident in responses with missing or contradictory data. This was despite the efforts made by the research teams to shorten, simplify, and contextualize the survey instruments.

Accessing existing firm-survey data from government agencies was a less-anticipated challenge. As noted in Table P.1, many teams identified the existence of firm R&D studies. Some of the surveys contained relevant micro-data that, if shared, would have been helpful. Privacy concerns, data-extraction difficulties, or capacity to assist prevented some research teams from gaining access to firm data held by government agencies. In other countries, such as in Korea, the researchers benefited from government cooperation. There were also some cases where government agencies became interested in the research and commissioned follow-up studies (Kruss et al. 2009). As these differences suggest, the response from government was mixed in terms of their interest and ability to support the research teams. Movement in the direction of making government data more accessible would help to reduce the barriers to accessing useful data.

Future Research Directions

We asked key informants to identify future research directions and to indicate what they would have done differently. This section presents

recommendations on how to explore: the multiple links universities establish beyond industry; the quality of the links; the impact of UILs; and the ways research might inform policy learning.

The first suggestion was to move from a university–industry focus to a more expansive university–industry–societal focus. The present focus on industry links situated the studies in an established research programme that had to date focused on a few countries with large economies (e.g., the US and Europe). There was both a need and a novel contribution to make by widening this narrow focus to include low- and middle-income countries where most of the world's people live and economic activity takes place. Given this initial goal, applications of university research to industry was the explicit focus. However, researchers acknowledged that industry was only one of the many stakeholders with which universities interact. The focus on innovation, whether in the form of a product or a process, is not the exclusive domain of industry. For example, university links may lead to innovation in the public and social sectors. "Family" firms or small-scale agriculturists are two examples where "developmental universities" have and could play a role.

Kruss et al. (2009) and Nabudere (2008b) echo this point when they suggest that existing research focuses too narrowly on modes of interaction with firms for product innovation. This orientation results from the presence of firm R&D and innovation surveys, and the scarcity of comparable survey data for public and social-sector organizations. These authors suggest that future research could survey universities more systematically, and could ask researchers with whom they interact. In low- and middle-income countries that tend to have fewer formal sector firms per capita, links may be more prevalent with non-firm actors. Because the studies reviewed here find less extensive links with industry than occur in high-income countries, we should not extrapolate from this finding that universities are not embedded in societies in other ways. The future research agenda should aim to understand the multiple links universities establish with a range of industry and non-industry stakeholders.

A related point was to employ social network analysis within the research agenda. The firm and university surveys used in these studies defined an actor's external partners and the attributes of those connections. Network analysis would allow the firm or the researcher to define their links (e.g., with private firms or public organizations) and the frequency and salience of their interactions with external partners. In this way, social network analysis could be a complementary technique to understand and analyse relationships, links, and exchanges in a system.

The researchers felt there was scope in future research to better quantify

the importance of product or process innovation. At present, most studies are interested in knowing whether an innovation is new to the firm, sector, or country. These indicators are meaningful, but they do not quantify the impact. Does an innovation new to a country have more or less economic impact than an innovation to a company? Employing these already-in-use outcome indicators did enable teams to compare findings. As such, substituting the outcome variables was likely not seriously considered at the outset, but future research could break new ground by tackling the "so what?" question.

The high incidence of UILs, satisfaction with the links, and generation of product or process innovation from the links suggest that the links create value. Governments would like to promote these dynamics, but at what cost? If the financial or economic returns of UILs could be measured, the importance of the issue for science policy would become readily apparent. Reddy (2011, pp. 46–47) likely overstates the claim that, "There are still no conclusive studies, other than anecdotal illustrations, that the university–industry cooperation or the measures to encourage such cooperation such as the establishments of science parks have led to significant economic benefits either regionally or nationally." Nevertheless, Reddy's observation does present a challenge for future research: the need to better capture the impact of UILs.

One could envision other ways to generate findings that would support policy development. Numerous case studies (e.g., Brazil, Malaysia, and Nigeria) identified policies directed at university research, industrial R&D, or institutions such as intellectual property legislation. Future survey instruments could build on existing barriers and incentives (e.g., trust and proximity) and include a range of policy instruments that firms or universities might access. The effect of a given policy on firm or university performance could be measured by exploring multivariate analysis or qualitative research methods. Policy-instrument variables would not be relevant for comparative cross-national studies (e.g., countries A and B may have very different programmes and policies), but efforts to isolate the impact of various national programmes or policies would be useful for informing national science policy.

Finally, when papers compared findings between relatively more and less industrialized countries, authors tended to conclude that UILs in less industrialized countries did not have "very high and statistically measurable impact at early stages of the catch-up process" (Schiller and Lee, Chapter 2, this book). The implication is that economic structure determines the agency of firms–universities' interactions. Although this may be an empirically grounded observation, it is perhaps less useful for policy development than case studies that focus on how clusters of innovation

emerge and grow.[6] The implication here is that, in certain areas, the agent of innovation shapes the structure. The quote by Joseph and Abraham (2009) critical of the case-study bias of focusing on successful UIL partnerships in India is well taken. However, learning from cases where firms and researchers break with the status quo and create process or product innovation, arguably contributes more to policy learning than would survey findings showing low incidence of UILs.

Impact of UILs on Universities

The findings from the Latin America, Africa, and Asia comparative studies and the country case studies suggested varying degrees of entrepreneurial activity at universities, but when links were formed, researchers consistently reported benefits accruing to themselves and their universities. An even more encouraging finding emerged from the comparative study of four Latin American countries (Argentina, Brazil, Costa Rica, and Mexico) that highlighted the most effective UILs were those that entailed a bi-directional flow of knowledge (Dutrénit and Arza 2010). Having examined the bi-directional benefits and costs to both researchers and firms, the studies demonstrated that UILs deliver mutual benefits, at least from the perspective of those involved. Where feasible, this focus on the relational dynamics between universities and firms should be maintained in future research.

Striking the right balance between knowledge creation as either a public or private good poses a fundamental question about the developmental role of universities. In spite of the recognized advantages of UILs (e.g., generating new research questions and problems), concerns remain (Arza 2010). UILs might lead to an unhealthy reliance on private revenue, steering a notionally public-oriented research agenda toward private-sector interests. The threat of private appropriation of public knowledge concerns many scholars. In Arza's view:

> . . . 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. (Arza 2010, p. 480)

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[6] Illustrative of such approaches are Suzigan and Albuquerque (2009) for Brazil, and Intarakumnerd and Schiller (2009) for Thailand.

How PROs promote research with partners, in a manner that is consistent with their missions, often raises conflicting logics (Lam 2012). The on-going process of "trying and mistaking" at play in universities may give rise to better ways to balance ethical and financial tensions of private–public partnerships. Further empirical findings on the non-financial returns of UILs may add nuances to this debate.

CONCLUDING REMARKS

As the chapters in this book demonstrate, the Changing Universities research programme generated new insights on the industrial use and importance of university knowledge in low- and middle-income countries. The teams made an important contribution, and their efforts continue to catalyse further research in this domain. In retrospect, it is somewhat surprising that this research agenda, given its relevance to science, education, and industrial policy, has not been funded by more national governments, particularly as governments are increasingly looking to industry and universities to drive economic prosperity.

The purpose of this chapter is to guide future research by reflecting on the experiences of researchers involved in an international research programme. We highlighted what the researchers did differently from existing research to yield new insights, and what they might do differently in future. Originally conceived as three regional comparative studies and several country studies, the Changing Universities programme spurred new research projects and collaborations, made conceptual contributions, generated novel findings, and influenced several governments to apply the UIL lens to higher education and industrial policy.

Their forward-looking suggestions will challenge researchers in several ways. If the challenges are taken up, conceptual developments and empirical findings will undoubtedly lead to a richer understanding of the flows and use of knowledge. Going beyond entrepreneurial links, to include an expanded set of relations that reflect the embedded reality of many universities in social, cultural, and economic life, could yield significant contributions. To move in this direction, we have discussed several suggestions, such as employing social network analysis to better understand the sectoral diversity, frequency, and strength of university links. Another recommendation was to refine the qualities and significance of several key indicators. For example, the prevalence of UILs in an industrial sector, and the kind of innovation reported (e.g., new to firm, process, or product innovation), could be further developed through quantitative and qualitative means to unpack the significance of links, and their resulting impacts.

As the chapters in this book illustrate, the findings make an important contribution to an empirical understanding of how universities are linking with industry, and in doing so, prompt a reconsideration of some long-standing normative questions. For example, researchers and industry representatives offer insights into the appropriate roles of universities as drivers of development, and question whether a commitment to public knowledge is threatened when PROs collaborate with industry. These insights, from different organizational perspectives and countries, invite further reflection on important normative questions surrounding the desired functions and contributions of PROs.

For a funding agency, this programme shows the important contribution that comparative primary data can make to catalysing research. Supporting data collection across numerous countries had a positive multiplier effect on research collaboration that was not anticipated. Early funding support to bring research teams together to discuss their plans might have contributed to strengthening collaboration, but the opportunity to share and compare findings led to new directions and research projects. At the same time, making full use of primary data poses a challenge for funding agencies. Numerous funding agencies now promote open access of research findings, but few agencies have systems in place to promote open data. Supporting secondary use of primary data through open-data repositories could further stimulate interest in topics that remain understudied because of data gaps.

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Index

Developing National Systems of Innovation

'What is similar and what is different about the relationships between how universities and public laboratories interact with firms in developing, as contrasted with advanced, industrial economies? How do these differences reflect and support the differences witnessed in on-going innovations? This book is the first large-scale report on these matters, and their implications for policy in developing countries.'

From the foreword by Richard R. Nelson, Columbia University, USA

Interactions between firms and universities are key building blocks of innovation systems. With a focus on developing countries, this book presents novel comparative research spanning three continents. The result is a more universal and dynamic view of the shaping and reshaping of interactions between firms and universities within different countries at various stages of development.

Through expert contributions, a combination of empirical investigations and theoretical discussion are presented, existing studies on innovation systems are quantified and further avenues of research suggested. Readers will establish a more universal understanding of the vibrant relationship between firms and universities, and how this results in innovation for the future.

Scholars of innovation, evolutionary economics, science and technology studies, and development studies will find the original research to be of great value. This book will also appeal to public research organizations and policymakers.

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